Oxy-Acetylene Torch Practice

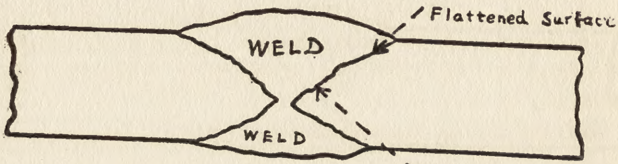
J. F. SPRINGER

671

Welding

160

ositions. We may learn a lesson in economy here. If we use too large a tip and thus waste oxygen and acetylene, we are of course wasting money. Our endeavor should be to reduce conduction away from the working point and thus conserve the heat from the torch. In case work has to be heavily clamped in the immediate vicinity of the joint, it may accordingly often be economical to interpose asbestos or mica. Or, it may be possible to reduce the actual contact of the clamping surfaces by grooving or corrugating them.



Overflow Weld

Similarly, if the under surfaces at the joint are supported on a metal table or other good conductor of heat, we may often reduce the conduction away from the working point by making a groove or channel all along beneath the joint. Thus, in a certain oxy-acetylene welding machine used by the Edison Storage Battery Co., a groove is arranged in the metal support beneath the location of the seam. Air is a very good non-conductor, so that if actual support is not needed under the seam it is quite suitable. If support is needed, asbestos, mica, or some other non-conductor may be used.

The weld will often be somewhat weaker than the adjacent work. This is sometimes remedied in part at least by building up the volume of new material. Metal is frequently added until the upper surface is made convex. Additional attachment may be secured by continuing the excess over to each side of the seam. Of course, the upper surfaces of the work must be heated to a molten state to provide good attachment.

Another method of strengthening the weld is to bevel and weld the edges both from above and below. There will thus be two V's—one above, the other below. The two grooves are dealt with separately, turning the work over for the second weld. Each weld is rounded and material attached to the work by overflowing—as described in connection with the single groove.

It should be mentioned that the bevelling of the edges of the work, if of steel, can often be accomplished by the use of the cutting jet. This procedure leaves an oxidized skin. Preferably this should be removed in advance of welding operations. Ordinary steel is, apparently, unaffected beyond this skin. Hard steel will probably experience a reduction in hardness; the carbon content seems to remain as it was. It is important that the edges of the work be clean. If they have been *chipped* off, nothing further will be necessary. Under other circumstances, it may be needful to clean with a suitable acid solution.

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Leak in Pressure Pipe

This and other leaks successfully sealed by Oxy-Acetylene process

Oxy-Acetylene Torch Practice

A Book for the Men Who Use
the Oxy-Acetylene Welding
and Cutting Torches

By

J. F. Springer

Prepared with the Co-operation of
The Davis-Bournonville Company
New York

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Table of Contents

Preface

THE object in view in *Oxy-Acetylene Torch Practice* is to furnish an account of the approved practice in oxy-acetylene welding and cutting. The application of the oxy-acetylene torch is a new art. In many directions, the methods have become more or less standardized, so that directions can be given in detail and with confidence. In other directions, the practice is somewhat tentative, and the exercise of judgment is necessary in dealing with particular problems. Here the knowledge of general principles will often be of service. It is hoped that the present little book will be an up-to-date guide to the actual user of the torch, supplying him with detailed information covering most of the important procedures which have been thoroughly worked out, and a real helper in regions where something yet remains to be done.

The Davis-Bournonville Company of New York and Chicago, themselves actual users as well as manufacturers of oxy-acetylene apparatus, have gone over the MS., giving especial attention to the methods and procedures of welding and cutting described. From their own experience as practical welders and cutters, and also from their knowledge of the art, they are satisfied that these methods and procedures are prac-

tical. The book as a whole has, therefore, their indorsement.

Where the text makes statements with reserve, the reader is to note the fact and act accordingly.

Acknowledgment is here made of indebtedness to various sources of information. Especially to be mentioned are *Autogene Metallbearbeitung,* a German periodical, and Johann Schwalb's article in *Mitteilungen über Gegenstände des Artillerie und Geniewesens,* an Austrian publication. Other acknowledgments are made in the body of the book.

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Introduction

THE gases used in oxy-acetylene welding and cutting are oxygen and acetylene. Oxygen ordinarily costs more than the other gas and should consequently be used with some care. Fair average costs for acetylene and oxygen are 1 cent per cubic foot for the one, and 2 to 3 cents for the other. Oxygen can be made at or near the point of use by employing suitable generating apparatus. Or, it can be purchased compressed in cylinders. There are several methods of manufacture. Albright, Son & Co., Allentown, Pa., make their own oxygen. Using chlorate of potash ($KClO_2$) at $0.0925 per pound and manganese dioxide (MnO_2) at $0.0275 per pound, they find that the total expense—including fuel, labor and freight—is $1.3075 for 56 cubic feet, or $0.0233 per cubic foot. The Worcester Pressed Steel Company, Worcester, Mass., manufacture their acetylene at a cost of $0.008 per cubic foot.

The various tips consume of course varying amounts of gases, the variation being due in part to size of tip. The Vilter Manufacturing Co., Milwaukee, Wis., give the following figures showing the costs per hour of operating the Davis-Bournonville torch. The costs include depreciation, but not labor.

Expense of Operating Welding Torch

Size number of tip.	Cost per hour.
1	$0.54
2	0.62
3	0.83
4	1.05
5	1.33
6	1.70
7	2.15
8	2.62
9	3.47

These costs are based on oxygen at 2.5 cents and acetylene at 1 cent.

If acetylene is employed at various points in the shops, it should be carried to the vicinity of the point of use by fixed metal pipes. Flexible tubing will then be used for the purpose of connecting with the torch itself. Usually, a flexible tube carries the oxygen from a portable cylinder to the torch. Regulators are employed in connection with both gases to control the working pressures. There should be two indicators used with the oxygen—one to show the pressure in the oxygen cylinder; the other, to show the pressure of the oxygen as it flows into the torch. The manufacturer will, or should, specify the pressure to be used with the various sizes of his torch. Follow his directions, unless you have some very solid reason to depart from them; it is to his interest to give the best possible pressures. There are, occasionally, solid reasons for departure.

The oxy-acetylene flame should be kept in an exact standard condition. This regulation is effected by

means of the cocks on the torch itself. Whether the flame is in exact standard condition, is readily determined by its appearance. Learn the appearance of the standard neutral flame. First, light the acetylene at reduced pressure, no oxygen being turned on, then set the oxygen regulator at the desired pressure and open the oxygen cock full. Then, open the acetylene cock sufficiently to get two white cones in the flame. Close the acetylene cock gradually, while carefully noting these two white cones. When they merge into one, the result with a high grade torch is a neutral working flame. It is now in proper condition for the usual welding operations upon steel, etc. If there is an excess of acetylene, the steel will be more or less carbonized; if there is an excess of oxygen, it will be oxidized or burnt. The operator should not be content with a correct adjustment of the flame at the beginning of his work, but should give strict and repeated attention to this matter. If the workman is in doubt he should open the acetylene cock on the torch until the double cone appears; then close it gradually until exactly the stage is just reached where the single cone appears clearly formed. After a little experience, it takes but a moment to correct the adjustment. It is a great advantage that we have a sensitive and easy method of determining the neutral flame.

It is important to select the size of tip suited to the work in hand. Other things being equal, the tips vary roughly with the depth of the weld to be made. Choose the tip in accordance with the maker's directions, until you have found by experience that a different choice is warranted.

An improvement in torches which has lately been

introduced is concerned with the method of making the joint between the detachable tip and the tip holder. It has been customary to rely upon screw threads alone. One objection to this method is that such joints have some tendency to become leaky. A further objection is based on the fact that where an exact position of the tip in the holder is necessary, this position is liable to fail of realization when the tip is screwed home with a good deal of force. A new device meets these objections by the use of a conical seat for the tip. That is to say, the inner end of the tip is provided with a conical surface. The torch head is likewise provided with a conical seat, the two conical surfaces being exact counterparts of each other. Further, the angle of the conical surfaces is made sufficiently large to eliminate any tendency to stick, however hard they may be forced together. The sealing is effected by the close contact between the conical surfaces.

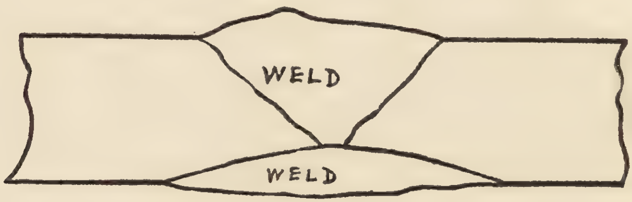
CHAPTER I

Ordinary Welding

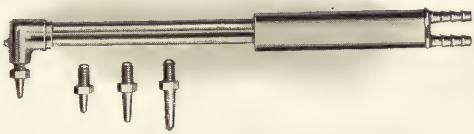
THE oxy-acetylene welder provided with a torch which furnishes a working flame at whose tip is a temperature of about 6,000 degrees Fahrenheit, has a magnificent tool with which to operate. The workman must remember, however, that though he has a tremendous *temperature* he does not have a tremendous *amount* of heat. Still he has a very considerable amount; and as to it he must be on his guard as to the way he manages. Because of the high concentration, he may easily overheat the metal at one point and underheat it at another. If the work is thin, he may easily melt through it in spots. With some metals, especially steel, too high a temperature would probably injure the quality of the metal involved. Because the *amount* of heat is not excessive, he may, especially if the work be heavy, lose much heat by conduction and radiation and in consequence find difficulty in getting the metal to the temperature desired. The student of the subject will understand from the foregoing that the oxy-acetylene torch is not an instrument permitting of careless handling. On the other hand, the necessary skill and judgment required are quite reasonable.

Oxy-acetylene welding ordinarily differs from the welding with which the blacksmith is familiar. The

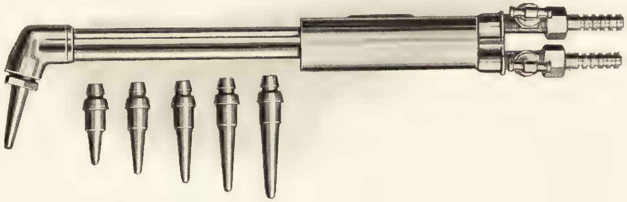
blacksmith does not bring the metal to the melting point; he brings about union in part by the blows of his hammer; the particles are forced together. In ordinary oxy-acetylene welding, neither the hammer nor its equivalent is necessarily employed. It is necessary then that the metal at the surface where union is to take place shall be molten. The blacksmith often adds no new material. In a large percentage of cases of oxy-acetylene welding, additional material is em-



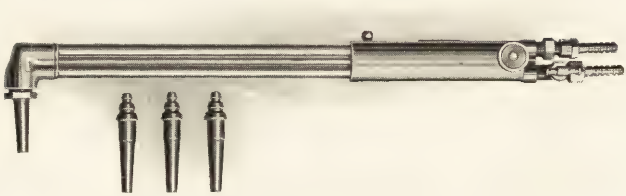
ployed. That is to say, the surfaces of the work are not directly joined. They are, as it were, soldered together by means of fresh metal. Great liberty is permitted in choosing this new material. It may be identical with the work or nearly so; or it may differ. This new material is melted in between those surfaces of the work that are to be united. The molten surfaces of the work and this fresh metal in the molten state unite because *both* are fluid or nearly so. It will be gathered from this that it is highly important that the faces of the work shall be sufficiently heated. Further, it is very necessary that the whole of the faces be brought to the high temperature. If the faces have failed to reach the melting point in spots, we will have



Midget torch, designed for very light sheet and metal welding



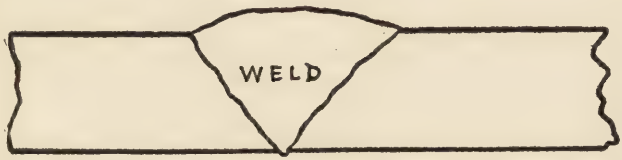
A very recent design in welding torches. Tip has conical seat in head



A very recent design in cutting torches. Two hose are employed instead of three

a defective weld. It is necessary, too, that there be no unmelted spots at the moment when the fresh metal is applied. All of this will be cared for, if the operator bears in mind that proper union is only to be expected where new and old materials are *both molten at the moment of contact.*

Consider a typical weld of, say, cast iron. The edges to be joined are beveled off at an angle of 45 degrees, so that a V-shaped groove is formed, the angle



Single Weld

at the point of the V being 90 degrees. At the bottom of the groove, the two faces of the work are in contact or nearly so. The very first thing to do is to melt some of the material from the faces in order to seal the bottom, for a distance at least. We now heat the faces and if need be the top of the material just melted down from the faces, so as to form a molten surface for the attachment of new material. The new metal in the form of a rod is now melted onto this surface. The V will thus be further filled up. This process is continued, the workman bearing constantly in mind that the new molten metal must be added to metal that is also in a molten condition.

In heating the surfaces for the reception of fresh material, the torch should ordinarily be so handled as

to swing the little working flame round and round in rather small circles, and yet to move slowly onward. In this way, the intense heat will be distributed over the desired surface. The object is to melt but not burn. Practice and attention will greatly assist the operator in applying the heat evenly and in avoiding overburning.

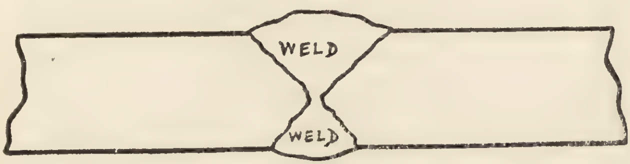
In handling the rod of new material, it is ordinarily advisable to keep the lower end constantly in contact with the work. The object of this is to avoid burning the new metal by providing an opportunity for heat to pass off into the work. Otherwise, the small rod might often become excessively heated. It is the high temperature of the little flame that makes the oxy-acetylene torch so admirable an instrument. The careless workman may, however, injure the new or the old material by not being on his guard as to burning.

Some judgment must be exercised in selecting the size of rod. If the rod is too small in diameter, it will be in danger of being burnt; if too large, the new material may become available so slowly that it will become difficult to keep the surface on which it is to find attachment in a sufficiently molten condition. Good sense will be the guide here.

The size of tip to use will turn largely on the thickness of the work. Heavy metal may ordinarily be expected to carry heat away from the working point. To offset this, the larger supply of heat from a larger tip should be brought into service. This will often result in the need for using a larger rod to suit the changed conditions.

To illustrate this point, suppose that sheet steel ½-inch thick can be advantageously welded by using a

certain size of tip and a certain size of rod, when we have simply these sheets with which to deal. But suppose the weld is to be made when these sheets are fixed in position with other metal attached beneath the joint. We have here the possibilities of increased conduction and radiation. When we seek to get a portion of the work to a melted condition, the heat will be conducted off more rapidly than before because there is more metal to do it; and, for the same reason, the loss by radiation will often be increased. Other

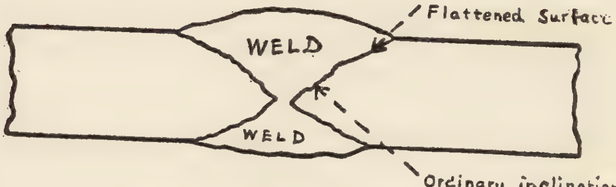


Double Weld

things being equal, a larger tip is the solution of the problem. This carries with it, usually, the selection of a larger diameter of rod. Conversely, we can readily see that conditions might undergo a change requiring a reduction in size of tip and rod. Thus, after trial had shown the sizes suitable, the weight of metal in the immediate vicinity of the joint might be reduced by the removal, say, of a supporting bar. Clearly, reduction of tip and rod are indicated.

Those who have followed these remarks will have little difficulty in seeing that the welding of free edges and the welding of the same edges held by heavy clamps placed close to the joint are two different prop-

ositions. We may learn a lesson in economy here. If we use too large a tip and thus waste oxygen and acetylene, we are of course wasting money. Our endeavor should be to reduce conduction away from the working point and thus conserve the heat from the torch. In case work has to be heavily clamped in the immediate vicinity of the joint, it may accordingly often be economical to interpose asbestos or mica. Or, it may be possible to reduce the actual contact of the clamping surfaces by grooving or corrugating them.



Overflow Weld

Similarly, if the under surfaces at the joint are supported on a metal table or other good conductor of heat, we may often reduce the conduction away from the working point by making a groove or channel all along beneath the joint. Thus, in a certain oxy-acetylene welding machine used by the Edison Storage Battery Co., a groove is arranged in the metal support beneath the location of the seam. Air is a very good non-conductor, so that if actual support is not needed under the seam it is quite suitable. If support is needed, asbestos, mica, or some other non-conductor may be used.

The weld will often be somewhat weaker than the adjacent work. This is sometimes remedied in part at least by building up the volume of new material. Metal is frequently added until the upper surface is made convex. Additional attachment may be secured by continuing the excess over to each side of the seam. Of course, the upper surfaces of the work must be heated to a molten state to provide good attachment.

Another method of strengthening the weld is to bevel and weld the edges both from above and below. There will thus be two V's—one above, the other below. The two grooves are dealt with separately, turning the work over for the second weld. Each weld is rounded and material attached to the work by overflowing—as described in connection with the single groove.

It should be mentioned that the bevelling of the edges of the work, if of steel, can often be accomplished by the use of the cutting jet. This procedure leaves an oxidized skin. Preferably this should be removed in advance of welding operations. Ordinary steel is, apparently, unaffected beyond this skin. Hard steel will probably experience a reduction in hardness; the carbon content seems to remain as it was. It is important that the edges of the work be clean. If they have been *chipped* off, nothing further will be necessary. Under other circumstances, it may be needful to clean with a suitable acid solution.

It sometimes becomes necessary or advisable to make a vertical joint. Such cases arise, for example when vertical breaks occur in a machine bed which cannot be moved. Vertical and inclined cast iron joints have been made. It will be of interest to con-

sider how success was obtained. The beginning is made at the lowest point. Here a block of graphite will be so placed as to cover say one-half inch of the groove which has been prepared for welding. The pocket thus formed is filled with new material from the welding rod in the usual way. Another block of graphite will now be put in place on top of the first. This second pocket will be filled with new material. By adding blocks of graphite one at a time and successively filling the pockets thus formed, the welding can be carried up the joint.

CHAPTER II

Pre-Heating

IT is often a misuse of the oxy-acetylene torch to employ the little working flame to heat the work through the range of temperature beginning with the temperature of the surrounding atmosphere on up to, say, red heat. It is frequently much more economical to perform this part of the heating by the use of some cheaper method and then to complete the heating with the torch. The methods for securing this pre-heating are, some of them, commonplace enough. Conditions will at times favor one method; and at other times, other methods.

In pre-heating a large cast iron kettle, a charcoal fire was employed. The kettle weighed upwards of 18,000 pounds and the metal in the region of a crack two or more feet long was several inches thick. The crack was in the bottom. To deal with it, the kettle was overturned. The pre-heating was done from within and was directed against the involved region. Pre-heating was not merely economical here: it was probably essential, because of the necessity for furnishing a very considerable amount of heat. To protect the operator from the radiation, asbestos sheeting was employed. In repairing a break in a locomotive cylinder, the pre-heating was also done with charcoal. A

temporary oven was built up of loosely laid brick. A fire was started and kept going for two and one-half hours, when a dull red heat was secured. This condition was then maintained for six hours longer during the welding operation. (See Fig. 1.) It is often permissible to use an ordinary blacksmith's forge for the pre-heating operation. If a great many similar cases are

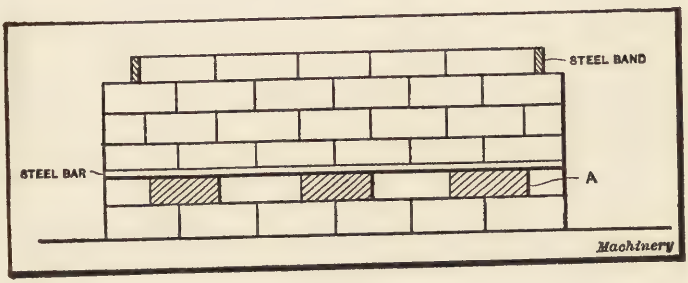


Fig. 1

to be dealt with, a special forge and bellows can be rigged to suit the conditions. But we are not limited to charcoal. There is the torch using illuminating, producer or natural gas, the oil torch, the gasoline torch. In fact, any reasonable method of getting a large amount of heat but not necessarily a high temperature is to be considered. In welding a break in a locomotive engine frame, a gasolene torch was employed to pre-heat. The assistance of the torch was continued throughout the welding operation. Where the work is repetition work, the peculiar conditions can often be more closely met by a special arrangement of pipes and burners.

If the only object sought is an economical one, great latitude in methods, fuel and arrangements is permis-

sible. One may have to pay attention to the character of the metal and be particular as to choice of fuel because of possible effects upon the quality of the material of the work. The principal object sought is to get an abundance of heat and a moderately high temperature. A European method of manufacturing tubing with the aid of power driven gas welding machines provides for the passage of the rolled but unwelded tube through a muffle or past other heating apparatus just before reaching the torch. The tube is a bright red when it passes under the torch. Sometimes the outer flame of the torch itself may be used for preheating. Thus the Edison Storage Battery Co. employ a machine already referred to in welding a straight seam on the containing cans of their batteries. The torch, the work and the clamping device are so arranged that the outer flame of the oxy-acetylene jet is divided into two long streamers. One of these lies on several inches of the seam before it reaches the working flame. It is quite possible that this arrangement was not provided with a view to pre-heating. That is not important. The forward streamer does pre-heat and this fact must make possible a quicker passage under the working flame and a consequent economy in gas consumption. We have here what may be quite important. The outer flame is the scene of the generation of a fair *quantity* of heat, although it may suffer losses through the formation of water vapor, etc. The intelligent user of the oxy-acetylene torch should consider whether his work may not permit the utilization of this flame in some way. In the machine referred to the clamps arranged along the sides of the seam are beveled to afford access to the torch. The bevels are,

however, quite steep—about 60 degrees. The writer may suggest, then, in connection with hand work, that similar clamping bars be so formed as to provide a canyon-like working groove.

Again, in the hand welding of the larger sizes of tubing, it would be practicable to provide a series of gas jets on a single supply pipe arranged beneath the joint. By this means the edges could be pre-heated with cheap gas.

Pre-heating is, however, often provided for reasons other than those connected with economy of gas consumption. It is used as a means of dealing with the otherwise bad effects of expansion and contraction. Almost all substances expand as they are heated and contract as they are cooled. Thus a round steel rod will increase in length and diameter about 0.0000066 for every Fahrenheit degree that its temperature rises. If its length is 12 inches at 100 degrees, it will have increased at 2,100 degrees an amount equal to 2,000 times 0.0000066 of its length—or 0.1584 inch. That is to say, the bar will be more than an eighth of an inch longer. The diameter will have increased in the same proportion. In fact, a rise of 2,000 degrees in the temperature of almost any metallic body will occasion very considerable expansions in every direction. It will be longer, thicker, wider. A little thought will soon convince one of the fact that a sudden swelling and resultant shrinking of only a small part of the work may, at times, have disastrous results.

Take a rather common case. A spoke of a fly wheel has had a piece broken out. This piece just fits into its place. If we make our grooves and these fill up with new metal, thus making an apparently good

weld, we may soon find out that the cooling off process will give rise to so much contraction that a break will occur in the weld or at some other point. Again, suppose we have a crack in a casting. We chip it out in order to get our beveled edges. We heat the faces and fill in with new molten material. What will happen when the weld gets down to the ordinary atmospheric temperature? Evidently the new material will be shorter, narrower and shallower. We may expect then a shrinkage away from the walls of the crack.

Now what is to be done to meet the conditions? If we could heat the whole of the work, within as well as without, equally at the same time, we should probably have an ideal solution. But one of the great objects in oxy-acetylene welding is to localize the heating. We may often come in between and pre-heat not merely the immediate vicinity of the location with which we are to deal but a larger portion of the whole. In this way we seek to distribute the stresses and strains. Thus, in the case of the wheel, we may heat the parts of the broken spoke, the adjacent spokes and the intervening rim to, say, a red heat. We do not bring everything to the same temperature, but seek to have it shade off. Otherwise our pre-heating would itself perhaps introduce stresses and strains too severe to be endured without breakage. We have in this way lengthened the distance between hub and rim along the broken spoke. Consequently, when we fill in the new material to make the joints, we shall have a longer spoke than will be needed at atmospheric temperature. It has opportunity for contraction because it and the adjacent spokes are going back to normal size together. The shrinkage will differ in amount at various points

because of the purposely arranged variations in temperature. A little expansion and a little contraction on the outskirts, and greater amounts towards the weld. In the case of the crack, we may, if conditions are favorable, heat the metal beyond each end of the crack. If properly done, this will ordinarily have the effect of opening up the crack. Sometimes it may be sufficient to heat at one end only. The object is to enlarge the crack, so that when it is filled with new metal the amount of such material in the weld will be sufficient when it cools off to fill the original space. Ordinarily, the walls of the crack should be held apart until the weld is completed. The width of the crack and the width of the new metal will then contract together. If the crack runs from a point within the periphery all the way to the edge, we may at times open up the crack by heating at a point a little further in than the point of beginning. Commence welding at the inner end of such a crack and work towards the edge of the casting.

It is important to remember that pre-heating of this sort should ordinarily be done rather slowly. The expansions then have time to distribute themselves and the movement of particle from particle will be kept very small. If the work is quite heavy, we must reflect that the outside will heat before the interior. If we raised the temperature of one part much more than that of the other, there would be a considerable difference in the amounts of expansion. When such conditions exist, we are in danger of having breaks. The remedy is to heat slowly so that within and without the distribution of heat may proceed in a fairly uniform manner. A slow heating is especially to be advised where there is a combination of thick and heavy parts.

Otherwise, we may expect severe strains and perhaps breaks.

Similar remarks apply to cooling. Safe cooling is slow cooling. We may retard cooling by the use of

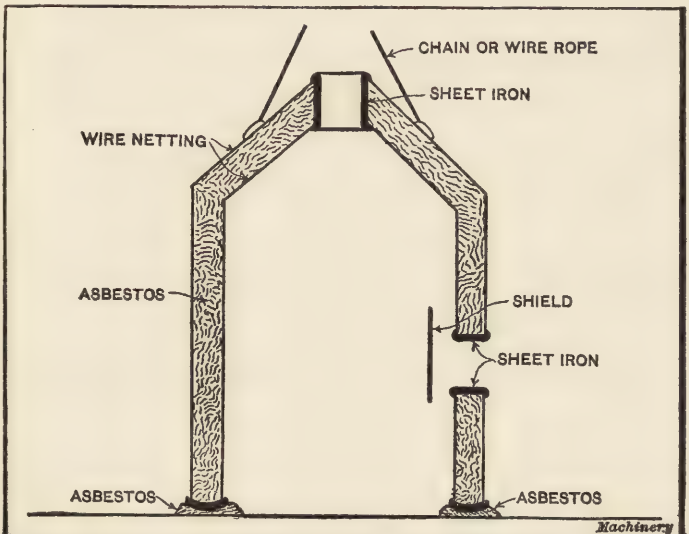


Fig. 2

asbestos sheeting or by packing in heated ashes or heated slacked lime.

If possible, pre-heat the entire casting. This seems to be the very best way of taking care of expansions and contractions. A practical method may here be given of dealing with the pre-heating of castings whose

size makes necessary special arrangements. The casting is placed upon a bed of fire brick, which have been arranged with spaces between them. A kind of temporary wall or furnace is then built around the whole. Fire brick is used here also. They are arranged, of course, without the use of mortar in such way as to provide narrow openings between them. Flat steel bars may be employed just above the course of separated bricks. The uppermost course may be held in place by an enveloping band of steel. The object of the open spaces is to produce a draft. Charcoal is now filled in between casting and wall, and the fire started. A sheet of asbestos is laid on above to cover the whole. This cover should be provided with a number of holes in order to permit exit for the gases. In this way the whole casting may be heated and made ready for the welding operation. If the floor is a wooden one it will be necessary to protect it.

Another procedure requires a hood made of a poor conductor of heat. Such a hood is shown in vertical section in Fig. 2. The walls of this hood consist of two sheets of wire netting with the intervening space filled with asbestos. A suitable vent hole is arranged at the top. This may have its wall of sheet iron. Another aperture, also lined with sheet iron, is provided on one side of the vertical cylindrical wall. The bottom of the hood is furnished with an annular base of sheet iron. The netting and sheet iron may be joined by welding. A means of lifting and lowering the hood should be arranged. The hood will be let down over the casting which is to be pre-heated. In order to make a tight joint with the floor, some loose asbestos may be arranged as a footing for the hood.

A kerosene or other torch may now be directed in through the side aperture in such way as to strike the casting on a tangent. Or, a kind of shield may be provided just inside the side opening with the view of dividing the flame. In either case, the object is to encircle the casting with the flame of the torch.

It may sometimes be advisable to arrange auxiliary fires on shelves above the main fire at the bottom. This procedure is especially to be recommended where the casting is a tall one. The object of distributing the fire is to avoid a severe concentration of heat at one point. An effort should be made to apply the heat slowly. Consequently, the fires should not be too quickly brought up to their maximum. Let the fires be started in a moderate way and increased in strength gradually.

When the welding has been completed, the hood may be lowered into position again and used as a means of retarding the cooling. The oil torch should be brought into service again for a period. It may then be shut off and the openings of the hood covered. In this way, one seeks to provide a slow and even cooling. In fact, whether the casting has been pre-heated by means of the hood or not, it is important to take care of the cooling in a proper manner. In general, re-heat the casting just as soon as the welding is completed and before it has had time to cool much. Then cover it completely with asbestos. For this purpose, asbestos wool or scrap asbestos may be employed. Or, the casting may be buried in any of the materials used ordinarily in retarding the cooling of steel which it is desired to anneal. If the form of the casting is of such a character that cracking is not to be feared,

it may often be cooled in the bed of charcoal in which it may have been heated.

Cast iron may be heated to 700 or 1,000 degrees, Fahrenheit. Generally speaking, the higher the temperature of pre-heating, the less danger from cracking when cooling. Aluminum castings should be pre-heated to a temperature of about 600 or 700 degrees. If possible, maintain the heated condition during the entire time of welding. In carrying out this requirement, it will often be found of service to cover the casting with asbestos: leave exposed only the working area. Asbestos sheeting will be found very serviceable in keeping any work hot during welding, whether it is of aluminum or not.

It will be instructive to consider a case of heavy welding performed by the Pullman Company of Chicago. The bed of a hydraulic press was cracked. This casting weighed about 10 tons and the crack was about 10 inches long and 26 inches deep. The material of the bed was cast steel. The casting was placed on supports of brick about 14 inches high. A fire of wood and charcoal was maintained all night, with the result that when welding was begun the metal was red hot. A large tip (No. 10, Davis-Bournonville) was used in connection with soft steel welding rod. Two workmen were employed. The time consumed on the weld was about five hours. As steel may be cut by the oxy-acetylene process, the necessary enlargement of this crack was made in this way. The Pullman Company estimates the expense at $19.16. As their gas costs are extraordinarily low, I take the liberty of re-estimating the expense:

357 cubic feet of oxygen at 3 cents per cubic foot	$10.71
143 cubic feet of acetylene at 1 cent per cubic foot	1.43
Labor	7.40
Fuel for pre-heating and annealing	4.00
	$23.54

The expense of replacing the casting by a new one would have been about $600.00. They state that the results of the welding were "highly satisfactory."

CHAPTER III

Restoration of Steel

IT will be impossible for the oxy-acetylene operator to become a real expert in *steel* welding without learning methods of restoring overheated metal. He should seek to get all the solid information he can on this subject. The first thing to learn, however, is why the steel should need restoration.

If a piece of steel containing, say, 0.50 per cent. carbon be suitably prepared by polishing, etc., and then examined under the microscope, it will not be found the same everywhere. If the magnifying power be not too great, what you see will appear something like a map. There will be patches divided from each other by strips or bands. In the present case the total area occupied by the patches will be not greatly different from that occupied by the dividing bands. The bands and the patches differ from each other. The bands contain no carbon: they are pure iron. All the carbon is in the patches.

Now of course we have been looking at a surface. In the body of the piece of steel, we should have lumps or grains instead of patches. The pure iron would fill up the spaces between the grains. What we have in the piece of steel is very similar to what we have in a piece of concrete. If we saw the concrete through

and thus lay bare a section, we shall see patches and bands. The patches correspond to the pieces of rock in the original concrete; the bands, to the cement mortar occupying the intervening spaces. It is perhaps true that the comparison may be extended farther. There is some reason to think that the pure iron operates as a binding material holding the grains—or crystals—together.

The grains themselves have been found to consist of layers or films of pure iron and layers or films of a hard substance called cementite. The layers of these two substances alternate with each other: there will be a layer of iron, then a layer of cementite—and so on. These layers are incredibly thin. Indeed, they are so fine that they remained undiscovered until a few years ago.

Consider now what our piece of steel is like. We have a very complicated network of pure iron. The word "network" is not a very good one, as it suggests strings or threads. What we have are films or layers. Let us use "network" then with this difference in mind. We have first of all the main network consisting of the layers which separate grain from grain. Through each grain, however, numerous layers of pure iron run connecting the iron of the main network. In the case of our 0.50-per cent. carbon steel, the layers of iron in the main network are much thicker than those which run through the grain. Between the thin layers of iron lie the thin layers of cementite.

Now the grains of the very same piece of steel may differ in size in accordance with the treatment the metal has undergone. For example, if the steel has been heated to within 400 or 500 degrees Fahrenheit,

of the melting point, and then allowed to cool, the grains will be much larger than if we heat only to 1,500 degrees. In fact, there is an indefinite number of grain sizes. These vary in accordance with the temperature at which the heating is stopped. That is to say, for our particular piece of steel, there will be a range of grain sizes corresponding to the temperatures from about 1,425 degrees up to near the melting point—the higher the temperature the larger the corresponding grain size.

The reader will see the importance of the grain size upon learning that the strength of the steel decreases with the increase of the size of grain. This is a great fact and should be thoroughly grasped. Just why the strength should be less when the grain is larger is perhaps not fully known. The writer would suggest the following as perhaps a partial explanation. The total amount of pure iron in the main network probably remains about the same for any given piece of steel whatever the temperature from which cooling begins. The total volume of material in the grains would consequently also remain about the same. The distribution would vary for both. The larger the grains the smaller their total *surface* would be. This would make the *thickness* of the layers of iron in the main network greater. Let us ask ourselves the question, which will be stronger, a given weight of pure iron divided into thick layers, or the same weight divided into thin layers? We would expect, would we not, that the thinner the layers the greater the strength? If this supposition be correct, then we would seem to have some explanation of the increased strength of the piece of steel when the grain is smaller. However, whether

this be the reason why or not, the fact itself remains —the steel is strongest when the grains are smallest. This seems to be a general truth, good for pretty much all varieties of steel.

Now in the process of welding we have heated the steel on the faces of the V-shaped groove to or near the melting point; and the whole of the added steel has been melted. All this material we have heated to a very high temperature. The grain size will be at a maximum, and the strength at a minimum. The steel in adjoining parts of the work will have been heated to a high temperature, though not to the melting point. Indeed, we may have pretty much all possible temperatures from the melting point down, if we consider the metal of the work from the faces of the groove back. We may expect therefore all sizes of grain from the largest to the smallest. We will accordingly have all the corresponding variations in strength. The welder must face this matter. The problem is not, however, a peculiarity of oxy-acetylene welding. There is no system of welding that is exempt. The blacksmith will not heat to the melting point and will thus not produce the very largest grains. But he will get large grains and weaker metal. His use of the hammer in effecting actual union will no doubt be productive of some benefit. Any method in accordance with which a high temperature is reached may be expected to produce a large grain and decreased strength from the very fact of heating. The question of restoration will have to be dealt with if the best results are produced.

Now it *is* ordinarily possible to restore good steel to its original or best size of grain. This also is an im-

portant fact. If the metal has not been "burnt," it will usually respond to proper treatment. There are two general methods of restoration. First, there is the re-heating process; and second, the mechanical or forging method.

In order to apply the re-heating procedure, it is necessary to make sure that the steel has first been cooled below a certain pretty definite temperature. This temperature is about 1,275 degrees Fahrenheit. It is necessary that not merely the surface of the metal be cooled to this point but the interior as well. In fact, if we neglect any part, whether inside or outside, we can not expect restoration for that part. Now, ordinarily the cooling procedure is very easy to carry out, for the reason that we do not have to check it at 1,275 degrees, but may let it go as far as we please. So that by carrying it far enough, we are able to make sure that the whole is cool enough. We can cool to the ordinary atmospheric temperature, if we like. The same temperature of 1,275 degrees applies to all carbon steels whatever the carbon percentage.

In carrying out the re-heating, one does not have quite so easy a rule. We are in all cases, however, to reheat the steel to a point above 1,275 degrees. How far above depends largely upon the carbon content.

Re-Heating Carbon Tool Steel

If we are dealing with carbon tool steel, we simply heat it a little above, say 25 or 40 degrees.

It is a remarkable fact that steel loses its magnetic quality when sufficiently heated. The capability of being attracted by a magnet does not gradually disap-

pear. For ordinary purposes, it all goes at once. In the case of carbon tool steels, the temperature of disappearance is about 1,275 degrees. But this is just the temperature important to us in re-heating such steels. We have, then, the following rule:

Re-heat carbon tool steels a few degrees above the temperature at which they cease to be attracted by a horseshoe magnet.

We must, however, make sure that *all* the steel involved has been re-heated sufficiently. On the other hand, we must be careful that *no part* gets heated much above 1,275 degrees. How to deal with this requirement will be told later.

Re-Heating Medium Carbon Steel

If the steel has a carbon content within the range 0.50 to 0.90 per cent., then we re-heat it to a little above a temperature which we determine thus. For exactly 0.50 per cent. carbon, we take 1,400 degrees. For every 0.01 per cent. above 0.50 per cent., we subtract 3.15 degrees from 1,400 degrees. For example, suppose the steel has a carbon content of 0.55 per cent. This is 5 times 0.01 per cent. above 0.50 per cent. Consequently, we subtract 15.75 degrees from 1,400 degrees and get 1,384 degrees ($5 \times 3.15 = 15.75$). If the carbon content is 0.70 per cent., we must multiply 3.15 by 20 and subtract from 1,400. We thus get 1,337 degrees. If the carbon content is 0.90 per cent., we multiply 3.15 by 40 and obtain 126 degrees. Subtracting from 1,400, we get 1,274 degrees. Whatever temperature we get by calculating in this way must be slightly exceeded when we re-heat. Add a few degrees, say 25 or 40.

It so happens that medium carbon steels—i. e., those having a carbon percentage between 0.40 and 0.90—lose their capability of being attracted by a magnet at just about the temperature which we must exceed a trifle in our re-heating of these steels. Consequently we have the following rule:

Re-heat medium carbon steels a few degrees above the temperature at which they cease to be attracted by a horseshoe magnet.

Let it be remembered that the *whole* of the steel involved must be brought to the necessary temperature, and that *no part* must be allowed to rise more than a very few degrees above it. Directions as to how to accomplish these results will be found farther on.

Re-Heating Low Carbon Steels

If the carbon steel has a carbon percentage less than 0.50, we must slighly exceed a temperature higher than 1,400 degrees. The less the carbon, the higher the temperature. If the steel has only 0.10 per cent. of carbon, we re-heat to a temperature a little above 1,600 degrees. For every 0.01 per cent. in excess of 0.10 per cent., we subtract 5 degrees from 1,600 degrees to obtain the temperature which we must slightly exceed. For example, if the carbon percentage is 0.16, we have an excess in the carbon percentage of 6 times 0.01. Consequently, we subtract 6 times 5 degrees from 1,600 degrees and obtain 1,570 degrees. We re-heat steel at 0.16 per cent. carbon a little above 1,570 degrees. Again, let the carbon content be 0.30 per cent. This carbon percentage is 20 times 0.01 in excess of 0.10 per cent. Consequently, we must subtract 20 times 5 degrees. That is, we re-heat steel

having 0.30 per cent. carbon to a little above 1,500 degrees. For steel of 0.40 per cent. carbon, the temperature to exceed is 1,450 degrees.

Unfortunately, the horseshoe magnet alone is not an adequate guide for low carbon steels. The magnetic quality is lost before the re-heating has proceeded quite far enough. However, it is a guide for determining the temperature of 1,400 degrees, this point marking the cessation of the magnetic quality. For many ordinary purposes, we may depend upon the judgment for the remaining degrees. Let it be remembered that we are to heat 25 or 40 degrees above the temperature which we calculate to be that which corresponds to the carbon content. We have the following rule:

Re-heat low carbon steels to a temperature more or less above the point where the magnetic quality disappears, the amount of excess depending upon the carbon content.

As in the case of high and medium carbon steels, the warning is given that the *whole* of the steel involved must be raised to the proper temperature, and that *no part* must be overheated more than a few degrees.

Methods of Testing

Steel is a very complex material. It is impossible to make commercially a perfectly uniform metal. The carbon percentage may vary slightly. Even if we could be certain of the carbon, other substances such as manganese, sulphur, phosphorus, silicon will occur in varying percentages. Absolute uniformity of steel from one melting to another is practically unknown. Indeed, uniformity of the product from a single pour-

ing is not to be expected. One part of a steel ingot will differ slightly from another part. We have in these facts a partial reason, perhaps, why in re-heating it seems advisable to reach a temperature somewhat in excess of the theoretic one.

It needs to be emphasized that carbon is not the only substance in steel which controls the temperature of restoration. The statements and principles of the preceding pages are therefore to be regarded as general guides to the workman. They will probably cover usual requirements. There are other cases where the importance of the particular work in hand or the fact that a great deal of work is to be carried out with the very same steel will justify further efforts. Metallurgy does not seem as yet to have obtained a formula such that with its aid we may determine the best restoration temperature with exactness and certainty as soon as we know the chemical composition of the steel. It will be necessary therefore for the oxy-acetylene welder to get his information in another way. This is possible.

Heat one end of a 12-inch bar of the steel to a white heat in such a way as to have a range of temperatures down to and below black heat. That is to say, we heat the rod so that the first few inches of the cooler end will be distinctly attracted by a horse-shoe magnet while the succeeding portions will have higher and higher temperatures up to white heat. We should now have a series of examples of grain size, including the smallest size. In order to locate the region of smallest grain, we may either saw the bar into short lengths or plane off the outside metal along one side of the bar. In either case, it may seem best to polish the

surface in order to disclose the grain better. We look for the smallest grain. If the steel in question has a considerable percentage of carbon, we may notch the bar at short intervals before heating and break it apart at the notches upon cooling. The fractures will disclose the grain. We now have a sample of our steel in its best condition. If we wish to confirm our selection, we may test by mechanical methods a number of specimens, one having this grain size, others having somewhat larger sizes. Once satisfied that we have a specimen showing the grain when the steel is at its best, we use it as a standard.

We now need to know the temperature at which this size of grain forms. It will probably be near the point indicated by the rules already given. Accordingly, we heat a number of specimens to this temperature region. However, we heat to a series of temperatures 25 or 50 degrees apart. This may be done by using a thermoelectric pyrometer whose ends are fitted with sharp points. The pyrometer method, if the pyrometer is of high quality, is the accurate dependable way. Or, the workman may judge by the color. If the best results are to be obtained, this seems objectionable. Too much is required of the eye, and too much depends upon particular workmen.

How to Control the Temperature

It has been said repeatedly that we must get a certain temperature throughout the mass of the metal involved, but that we must not allow this temperature to be much exceeded anywhere. Without adequate attention, we are likely to fail right here. If, in carrying out our re-heating programme, part of the metal

is overheated, that part will have a coarsened grain and a reduced strength. If one part be not heated sufficiently, that part will retain the coarse structure brought about by the welding operations and will consequently not have its full strength. Either overheating or underheating will result in the steel being less strong than it should be. What we have to do is to bring the whole mass to almost the same temperature throughout. Of course, we are not concerned with that part of the work which has never been to a high temperature. That is to say, we do not have to cure metal which has not had an injurious temperature. A very safe rule to apply here is this: *All that part of the work which at any time lost its magnetic quality should undergo the treatment for restoration.* The horse-shoe magnet is a valuable aid here. In case there is doubt as to certain portions of the work, it will be advisable to include these in the restorative treatment. It is much better to include too much than too little. Re-heating properly carried out will have no bad effects upon the grain and strength. In many cases, it may be best to re-heat the whole article.

There are two or three ways of getting a given temperature throughout a mass of metal without exceeding this temperature more than a few degrees in any part of the mass. One method proceeds by *slow heating*. If we increase the temperature very gradually, we give time for conduction to do its work in the interior of the mass. How gradually will depend largely upon the thickness of the metal. The greater the thickness, the more gradually the temperature should be raised. If we can get at the metal from two sides at the same time, it will be well to do so. This cuts

the thickness in two. There does not seem to be any great necessity to do the first part of the heating with any considerable degree of slowness. But when we are within a moderate distance of the temperature desired, the temperature should be increased slowly. Indeed, it may be well enough to stop—but not recede—for a period. Supply just enough heat to maintain the temperature until satisfied that the interior has come up to the temperature of the outside. The final stretch may be gone through—quite gradually. A somewhat different way is to heat the exterior—from as many sides as possible—to the desired final temperature and then hold this point until the interior comes up. If the exterior is nowhere and at no time allowed to exceed the finishing temperature, it will not matter how long the operation continues: the inside will never get hotter than the outside.

Still another method proceeds by the use of a *heating bath*. We select some metal or other material whose action on steel is not objectionable, whose melting point is below the desired final temperature, and whose boiling point is above. A metal suitable for some cases is lead. Whatever the metal or other substance, we prepare a bath having just the finishing temperature wanted. It is possible to control the temperature of such a bath with a great deal of certainty. Thus the American Gas Furnace Co., 24 John St., New York City, has a device for the automatic control of such baths. The article to be re-heated may have its temperature raised by other means until only a hundred degrees, say, yet remain to be secured. The article may now be plunged into the bath and kept there until its temperature is, throughout its mass,

in agreement with that of the bath. If the conditions permit, we may deal with only that part which has really been affected by the welding operation. The bath is obviously particularly suited where the masses of metal are comparatively small. There are, however, many opportunities for its application under such conditions.

Cooling Off

It would seem to be thought by some that slow cooling is essential. Slow cooling is advantageous, no doubt, in avoiding cracks from contraction: it gives opportunity for adjustment and the like. There would, however, seem to be no especial advantage from the point of view of restoration alone. That is to say, if every part of the metal to be restored has been cooled thoroughly and then re-heated in such way that every part—inside and outside—has reached the temperature of best condition without exceeding it more than a few degrees, then a slow cooling would appear superfluous. The foregoing account has shown how these results may be attained. There is a quicker though less perfect method, however. The steel to be restored may be re-heated, subsequently to a thorough cooling, until externally it is well above the point of restoration. If the cooling from this point is now retarded, the interior will have opportunity to absorb heat from the exterior. In this way, the interior may perhaps attain the restoration temperature. And this is a good result. On the other hand, it has been attained at the expense of over-heating the exterior and producing there a condition different from the best possible. The oxy-acetylene welder is advised to use

this method only when a better procedure is, for some reason, impossible. It would probably in most cases be about as easy to hold the temperature of the exterior at the restoration point (annealing point) until the interior has come up to thermal equality.

Mechanical Treatment

It has been found that the grain size may advantageously be broken up by mechanical means. Thus forged steel and rolled steel are much stronger than cast steel. This fact is to be attributed principally to the reduction in grain size. Railroad rails are formed by rolling and are in consequence very much stronger than they would be if cast.

The methods of securing the very best results do not seem to have been as yet thoroughly worked out by steel metallurgists. At the same time, it will be well for the oxy-acetylene welder to understand the main features of what appears to be the best procedure. In the case of mild steels, mechanical treatment can be commenced at a high temperature. But, if begun, it should be continued without intermission, down to the point of final stoppage. The welder will use a hammer or some similar tool. Mechanical treatment should be stopped when the steel has reached the temperature corresponding to the finest or best grain size. Preceding paragraphs treat of this temperature. In any case, he has continued the treatment far enough, when the steel is attracted by a magnet. In some cases, he will perhaps have gone too far. The suggestion is made by the writer that the oxy-acetylene welder may find it useful to use a hammer head that has been

magnetized. A piece of hardened tool steel can be permanently magnetized. When the hammer begins to stick, it is time to stop.

The statement can not be made in any final way, but it would seem doubtful whether hammering during the progress of the welding operation is beneficial. Hammering or forging of the finished portions is recommended, if the foregoing directions are carefully followed. The annealing, or restoration, of the material which has been involved in high temperatures should, if possible, be carried out in all cases, whether forging has been done or not. The restorative effects of a thoroughgoing annealing process are very penetrative; forging is frequently not so.

CHAPTER IV

Copper and Aluminum

Copper

COPPER melts at about 1930 degrees, Fahrenheit. Pure, it is salmon colored. Its specific gravity varies in accordance with its condition from 8.2 to 9. Its capacity for heat is very great. Also, it is an exceedingly good conductor of heat. Normally, copper is tough and ductile. However, when heated, it enters upon a brittle stage at about 1650 degrees. This brittleness continues on up to about the melting point. In order to weld copper, we must pass into this critical zone. Furthermore, at these higher temperatures, copper possesses the remarkable capacity of absorbing certain gases. Thus, if exposed to the atmosphere when at a white heat, copper will absorb oxygen and become brittle because of such absorption. Copper is also remarkable from the fact that heating to a high temperature followed by quenching in water has a softening or annealing effect. But oxidized copper, though annealed thus, will begin to fracture if one attempts to hammer it. It will be readily understood then that it is of great importance to prevent oxidation. The outer flame of the oxy-acetylene torch is, indeed, one which is eager for oxygen. By proper management of it while welding, the operator may

succeed in preserving the new copper in the weld from oxidation. That the work may be perfect, however, it is necessary to preserve the old copper of the work as well. Here is where some difficulty exists. Because of its great conductivity as respects heat, a high temperature will be found to be present on either side of the joint for some distance. Unless the operator can succeed in protecting this outlying region, he will hardly produce a piece of perfect work. In other words, the thermal conductivity makes it difficult to localize the high temperatures, so that we look for methods of protection from oxygen.

It is well known that phosphorus has a great avidity for oxygen. If, then, instead of a very pure copper produced electrolytically, we use a phosphor copper alloy, we may expect good results. Wherever the exhalation from the phosphorus reaches, there we will have deoxidation going on. Again, we may use a welding powder containing a percentage of phosphorus and secure a deoxidation. I am not able, at this writing to give the exact results of investigations under way in Germany, but the copper welder will be glad to know even in a general way that good powders can be made of mixtures of such chemicals as borax, phosphor natrium and prussiate of potash. The borax meant is not commercial borax, but that which has undergone a high temperature in a crucible and has then been pulverized. Boracic acid may be used instead of the borax. Apparently, the powder is prepared by mixing the boracic acid and the phosphor natrium. Welding powders of this description are said to possess the property of forming a film over the work and thus accomplish the exclusion of the

Copper Kettle, 5 ft. 6 in. in diameter, 31 in. deep, used under pressure. Sheets at top $\frac{1}{8}$ in.. others $\frac{3}{16}$ in. All seams are welded inside and out.

atmosphere. It is recommended when welding copper sheeting to spread the powder containing phosphorus for about an inch and a half to either side of the joint. By means of the torch, this powder is then melted before the welding operation proper is begun. As there is some possibility of blowing some of the powder away when used thus, it may seem more desirable to apply it in the form of a paste.

Aluminum

Aluminum is a very light metal, having a specific gravity of only about 2.6, or about one-third that of iron or steel. Its co-efficient of expansion per Fahrenheit degree is very considerable, being about 0.0000129, or nearly twice that of steel. The melting point is about 1215 degrees, Fahrenheit. This temperature, it will be observed, is rather low. Aluminum forms an oxide known as alumina, whose temperature of fusion is excessively high—about 5400 degrees. Its specific heat is 0.214, or nearly double that of iron. It is comparatively weak in a tensional direction. Cast iron will resist a tension of 16,500 pounds per square inch; cast aluminum, about 10,000 pounds. Because of this weakness and of its high rate of expansion and contraction, aluminum is often a difficult metal to weld. It is the problem of cast iron over again, only more intensified. Its thermal conductivity is quite high, being comparable with that of copper. It will accordingly be seen that there may be difficulty in localizing the region of high temperature. However, this will occasion no especial trouble in most welding, since the oxidation of aluminum can be avoided by the use of a proper flux.

The formidable thing which must be kept in view is the excessive expansion and contraction. However, as compared with cast iron, the *total* expansion and contraction from 100 degrees to the fusion point is nearly the same. This is because the fusion point of cast iron is about twice as many degrees higher than normal temperature as is the case with aluminum. However, the changes take place rapidly with aluminum. The operator should study the methods for taking care of expansion and contraction with iron and steel, and apply them most rigorously when dealing with aluminum. The low temperatures involved in the work make pre-heating easy. Indeed, the operator must be on his guard lest the temperature of 1215 degrees be reached and fusion set in. It may be possible to make slight saw cuts here and there and thus assist in making the effects of expansion and contraction harmless. These cuts must of course be repaired when the main operation is completed.

A safe rule to follow is never to weld aluminum without a flux. If we attempt to dispense with the flux, we shall often find that little globules will appear. These consist of aluminum within a coating of alumina. To get rid of these by heat, we should have to raise this oxide of aluminum to about 5400 degrees temperature. It seems that removal by means of a road is ineffectual, as another globule immediately forms. In melting in new metal from a rod, it is good practice to keep the rod constantly submerged in the molten bath of the metal in the welding groove, which, it is recommended, should be much larger than usual. If no powder is used, the oxidation is then confined to the upper surface. However, the

approved procedure is always to employ a flux. The following has been recommended:

Chloride of sodium	30	parts
Chloride of potassium	45	"
Fluoride of potassium	7	"
Chloride of lithium	15	"
Bi-sulphate of sodium	3	"
	100	"

The welder must bear in mind that the fusion point of aluminum is very low. The working flame will, consequently, be properly kept further from the metal than is usually the case with cast iron and steel. The torch should be so adjusted as to furnish an excess of acetylene. There need be but little fear of carbonizing the metal, for the reason that the temperature of the work is comparatively low. The operator who has been unsuccessful need not despair. Others are welding aluminum as a matter of course.

CHAPTER V

Sheet Metal Welding

THE welding of sheet metal is one of the great lines of application of the oxy-acetylene torch. Such welding is done by hand and also by means of oxy-acetylene welding machines; it is done by adding new material, and also without such addition. Some work can be done in more than one way; other work preferably requires the adoption of a single method. Thus, the welding of very thin sheets is best accomplished by machine welding; the welding of 3/32-inch plates can be well done by hand or by machine, with or without a welding wire.

Butt Welding by Hand Without Wire

Hand welding of sheets less than 1/32-inch in thickness will ordinarily require such skill and rapidity on the part of the workman as to make it inadvisable, except in rather exceptional cases. In welding plates varying from 1/32 to 7/32 inch in thickness by hand, a welding wire will often be unnecessary. The edges are not to be bevelled. If the two sheets are to lie in the same plane when finished, they are placed edge to edge. If the joint is but an inch or so in length, the edges may be placed in actual contact throughout the

joint. Preferably the two pieces are securely clamped. The clamps will preferably parallel the joint. At the bottom where they are in contact with the work, they should come up close to the seam, so that only that part of the work is exposed to each side of the joint that is to be heated by the little working flame. These clamping pieces may be bevelled off from the work upwards to provide working room. The surface immediately beneath the joint should be grooved and left empty, or the groove may be filled with asbestos or mica. The object is to provide a non-conductor of heat and thus secure a concentration of heat upon the metal to be united. If the groove is filled with mica or asbestos and the work securely clamped down throughout the region of the seam, there will be an additional advantage. Atmospheric air is excluded from the under surface and oxidation accordingly hindered or prevented. In Fig. 1, a suitable arrangement is shown in cross-section. Sometimes it is inconvenient or impossible to employ clamping devices. In such cases, the work may be held in position by welding the seam in spots at intervals of a few inches. Ordinarily, the edges are left a little apart, the distance varying with the thickness of the sheet metal. This procedure is sometimes called "tacking." When clamping is possible, tacking should not be relied on where precision of form is essential. If the joint is rather long, the edges may be put into actual contact on one end and at a distance from each other on the other end. The size of the interval at its widest point will vary somewhat with the length of the joint. A good general rule requires that the separation be 2.5 per cent. of the length of the joint. Thus, a 10-inch

joint will require an opening of 1/4 inch; a 15-inch joint, an opening of 3/8 inch. For joints two feet or more in length, this percentage can probably be reduced. A little experimentation will show precisely the allowance required for any given conditions. The thickness of the sheets will perhaps play some part in the amount of the allowance required. Fig. 2 shows the arrangement of the plates.

Perhaps some explanation should be given as to the reasons underlying the requirement as to the opening on one side. The oxy-acetylene welder begins on the side where the two sheets are in actual contact and works towards the other. As he proceeds, the edges draw together. At the welding point they should be in actual contact. They are not brought together by any action of his. He or an assistant will relieve, from time to time, the pressure on the clamps at the far side. The metal in the weld just finished is continually cooling and consequently contracting. There is expansion, no doubt, at the point of welding, but this is insufficient in respect to the amount of metal affected to set up an adequate resistance to the contraction.

The metal for the crack between the edges must come from the sheets themselves, whenever we weld without wire. The loss may be very insignificant. However, it will operate to diminish the standard thickness along the seam. The loss in thickness may be reduced by distributing it. That is to say, the track of the little welding flame may be widened. Instead of holding the torch so as not to vary to right nor left, the operator may combine a circular and a forward movement. In Fig. 3, this movement is diagrammed. One

may use either a right or a left hand motion. In many cases this movement will be advisable or necessary, aside from any desire to distribute any loss. Especially will this be the case with the thicker sheets.

We have now effected a butt joint. Upon turning the work over, we shall find the appearance different. If the welding has been well done, there will be no irregularities. The edges will not perhaps be quite in contact; and between them, the fused material may not have gotten through far enough to make it quite flush with the under surface. In other words, we may find a very regular and extremely shallow groove. For some work, this groove would mean an objectionable line of weakness. In such cases, the operator may repeat the welding operation along this shallow groove.

In case it is desired to make the joint of full standard thickness without using a welding wire, it may be done in the following way. In fact, by an obvious extension of the method, an excess of thickness may be provided, if that is desired for the purpose of reinforcement or for some other reason. The edges of the plates will be so formed by upsetting, rolling or bending as to provide ridges of excess metal. These operations may be carried out as hot or cold processes as the quality of the material or some other reason may indicate. They are preferably performed by machine, unless special precautions are taken to make the forming process by hand an absolutely regular one. It is essential, in order to secure the best results with the greatest possible rapidity, that excess metal supplied shall everywhere be precisely the same in amount. When the additional metal is supplied by properly formed edges, we have ordinarily a procedure better than that

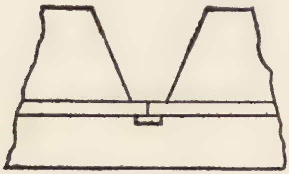


Fig. 1

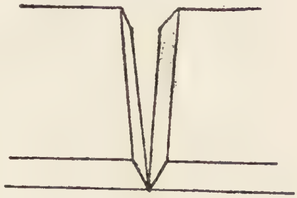


Fig. 2

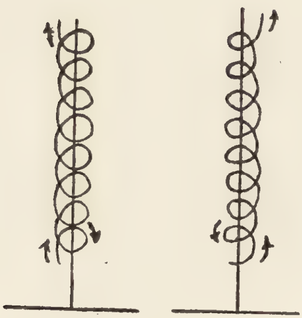


Fig. 3


Fig. 4


Fig. 5

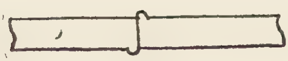


Fig. 6


Fig. 7

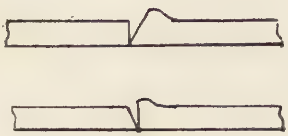


Fig. 8

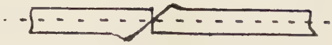


Fig. 10

Fig. 9

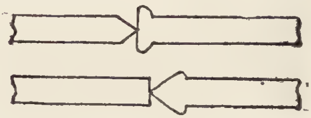


Fig. 11

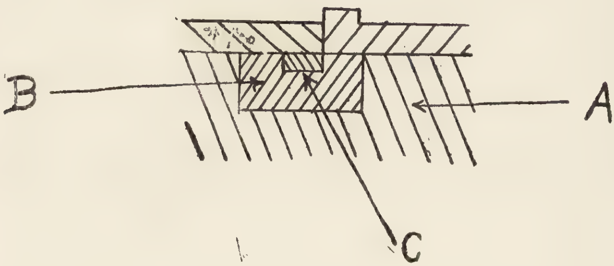


Fig. 12

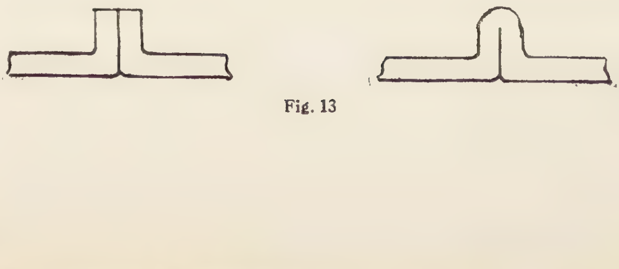


Fig. 13

which calls for welding wire. In the first place, the operator is relieved from the care of the wire, and can consequently devote his attention to making a better weld or to making it in better time. In the second place, the added metal is precisely the same as that of the work. In the third place, the amount supplied and the point at which it is supplied may be controlled with thoroughness and evenness. The position and amount can ordinarily be regulated better than with a wire. By providing the additional metal necessary for the seam from the work by means of formed edges, we shall often be able to use a class of labor of less skill than would otherwise be the case.

The simplest arrangement is perhaps that shown in Fig. 4. Here only one edge is formed. This form is to be applied principally to the thinner plates. If upon trial it is found that it is difficult to bring both edges simultaneously to the melting point, the arrangement shown in Fig. 5 may be employed. If there is no trouble from this source, we may weld on both sides by using the forms shown in Figs. 6 and 7. Do not depend upon these forms, if the edge of either sheet, including the added portion is thicker than 1/4 inch.

If there is difficulty in securing sufficient penetration of the heat, it will be well to form the edges in such way as to provide a narrow groove. The little working flame can then be made to reach the whole of the thickness. In Fig. 8 are shown two forms: the first requires nothing to be done to the one sheet; the other provides the bevel on the unthickened edge. But, just as in the case shown in Fig. 4, difficulty may arise at times because of unevenness in the heating of the two edges. This may be met by the form of joint

shown in Fig. 9. This corresponds to Fig. 5. Again, we may modify Figs. 6 and 7 and provide for penetration by the joints in Figs. 10 and 11. There is unevenness in the thickness of the two edges in some of the forms. This should be remembered in handling the torch, or another form may be used instead. Figs. 6 and 10 may be found to give but little trouble, as in reality the two edges are in both cases the same in thickness.

There may be reasons of considerable weight why such forms as those shown in Figs. 4, 7 and 11 would be of especial advantage to the manufacturer. In all these forms, the one edge is left undisturbed. The following suggestion is made as probably affording a corrective as respects unevenness of heating. Under ordinary circumstances, the table underneath the seam will be cut away so as to provide a groove as shown in Fig. 1. This groove is then left alone, or it is filled with some non-conductor of heat, like asbestos or mica. Now we modify this general procedure in such cases as those shown in Figs. 4, 7 and 11. We may, in fact, support the thinner edge by a conductor of heat. Such an arrangement is shown in Fig. 12. Here the metal of the table is shown at A. At B, we have the filling of asbestos or mica. As C, we have a strip of metal imbedded in the non-conducting substance. If this strip is of the same material as the work, it may be of approximately the same cross-section as that of the "added" metal of the right hand sheet.

In carrying out welding with the aid of formed edges, it may be found necessary in most cases to widen the track of the working flame in accordance with one of the diagrams of Fig. 3. In most cases,

it may be found of advantage to incline the working flame to one side in order to utilize its mechanical force in carrying the metal from the protuberance into the joint itself. With a little patience the intelligent workman will find his way in the matter of minor details.

It will be recognized by practical people that the preparation of the edges of thin sheets for welding without wire will require considerable care unless mechanical methods are employed to regulate the form and amount of the ridge provided. The Davis-Bournonville Company are bringing out a machine which upsets the edges of metal plates having a thickness of 1/16 inch or less.

It is impossible to say how far the preceding procedures may be carried. It will be safer perhaps to regard 1/4 inch as the maximum limit of the thickness of sheets that can be butt welded without the use of separate material. The future will probably disclose an advance.

An Equivalent of Butt Welding Without Wire

There is a method of making a joint which serves the same general purposes of a butt weld. It can be carried out with or without wire. In one form of this method, the edges of the sheets to be joined are bent up at right angles to the general surface to form a kind of flange. The two flanges, both being of precisely the same height, are brought together face to face. The edges are now simultaneously fused and a union made by the mingling of the material. Representatives of this joint, before and after welding, are

shown in Fig. 13. This method is employed by the Edison Storage Battery Co. in the fabrication of containers for their storage battery. This concern uses this joint on the longitudinal joint. The containers have a horizontal cross-section in the form of a rectangle with rounded corners. The longitudinal joint is vertical when the can is finished and in use. It is not located at one of the corners, but a little to one side. The material used is nickel-plated sheet steel of the thicknesses of 0.015 and 0.025 inch. The nickel-plating is done before welding. The longitudinal seam in question is perhaps 15 inches long. In this particular case, the welding is done by a machine. No wire is employed.

This type of weld is scarcely as strong as the ordinary butt joint. It will ordinarily be strengthened by diminishing the width of the flanges. Thus, the joint shown in Fig. 14 subsequent to welding appears stronger. In both cases, we may still further strengthen the joint by welding on the other side, if the form and size of the work make this practicable. In Fig. 15, we have on the left the result of welding the wider flanges from both sides of the work. On the right, the double-welded narrow-flanged seam is shown. If it is desired to have the second surface perfectly plane, we may use a welding wire to supply the additional material needed.

The flange method of making a joint is especially advantageous with thin sheets for the reason that the union is still made even though the operator's hand may linger a little too long here and there. The resultant ridge may not be perfectly even, but the weld itself is made.

Butt Welding by Hand with Wire

In the case of sheets whose thickness lies between 1/32 and 7/32 inch, inclusive, hand welding can be carried on frequently without wire and without beveling either edge. By means of wire, however, the seam may be brought to absolute standard thickness or may be thickened beyond standard. Ordinarily, the wire should be of the same material, or approximately the same material, as the work. This is especially important in cases of sheet steel welding where it is proposed to restore the steel by an annealing process. By considering the facts and principles of the chapter on *Restoration of Steel,* the reader will see that the temperature of restoration differs with different steels. It will be important then to have the metal which is added from the wire of such a character that the temperature of restoration for the work shall leave the new metal in a sufficiently perfect condition. Ordinarily, the thing to do is to use precisely the same material. For example, we may use a strip cut or sheared from the same sheet steel as that from which the work comes. If this can not be done, then seek to get steel having the same carbon percentage.

The general directions given under the heading *Butt Welding by Hand without Wire* in connection with clamping the work and allowing for the effects of contraction in all seams except very short ones may be followed in welding moderately thin sheets (1/32 to 7/32 inch in thickness) by the use of welding wire. Or, we may place the sheets with the edges parallel and at a slight distance from each other. The object of leaving a crevice is to permit the working flame to

fuse the material all the way through. The width of the crevice will vary from 1/32 inch up to, say, 3/32 inch. The edges are preferably clamped in such way as to be gripped to right and left and from end to end of the seam. If this can not be arranged, the sheets may be held in position by welding them together at spots separated from each other by intervals of a few inches. In selecting the size of wire, the operator should be governed by the thickness of the sheets. For sheets from 3/4 inch to 9/16 inch, use wire having a diameter of 1/4 inch. For sheets from 1/2 inch to 1/4 inch, use 3/16 inch wire. Sometimes the workman may have difficulty in obtaining at once wire of sufficient thickness. In such cases, it will often be permissible to twist two or more lighter wires together. In fact, there is an advantage in using a rope-like welding wire from the circumstances that such wire presents a greater surface to the flame and is consequently melted more readily. The rules as to sizes of wire are to be regarded merely as general guides. They will at times have to be modified because of the conditions. The general principle to bear in mind is set forth in what follows:

The heating of the edges to the melting point and the melting of the wire go on simultaneously. The size of the wire should be such as neither to retard nor unduly to hasten the operator in dealing with the edges of the work. An instance from actual practice may here be given to show how special conditions may enter into the question. The roof sheets of the steel cars being built by one of the large concerns for a leading American railroad were of sheet steel about 1/16 or 3/32 inch thick. There were many trans-

verse seams. In welding such transverse seams, which are slightly arched, trouble had before been experienced from the fact that, subsequently to welding these joints in position on the car, a very distinct tendency to form a gutter-like depression would manifest itself. To correct this, a T-bar would be employed beneath the joint. The edges of the roof sheets would be riveted to the arms of the T, and the welding performed afterwards. This method was employed on the cars in question. Under ordinary conditions a wire 1/16 inch in diameter would probably have been of sufficient size. But the T-bar in effect increased the thickness of the sheets. Because of the great increase in the ability to conduct and radiate away heat from the working flame, a more powerful torch or a slower movement was required. In either case, the 1/16-inch wire would have melted away too rapidly. As a matter of fact, 1/8-inch wire was used. That is to say, a wire four times as heavy as would have otherwise been necessary was the thing employed. That this concern was doing about the proper thing to avoid undue delay may be judged perhaps from the fact that 232 feet of roof welding per car, of which welding that described was typical of a large part or the whole, was done at the expense of 4 cents per lineal foot for the labor.

Welding of Medium and Heavy Sheets

Sheets having a thickness of 1/4-inch or more are generally welded by hand, with the use of wire, and by beveling the edges. One or two of the thinnest of these sizes may occasionally be exceptions, but that

is about all. The edges may be prepared in several forms. Perhaps the most usual method of making the joint is to bring together two single-beveled edges and thus form a V-shaped groove. These edges may be beveled at an angle of 45 degrees, thus producing a 90-degree groove. However, this angle of 45 degrees may be considerably increased or considerably decreased. It is largely a question of the convenience of the operator. The object of beveling at all is partly to enable the metal of the work to be fused all over the face of the edge from top to bottom and partly to provide a support for melted metal. In Fig. 16, the standard form of a 90-degree groove is shown. Variations are to be seen in Fig. 17. In Fig. 18, we have forms suited to double welding. It will be noticed that the combination of steep and flat grooves can be made, if the exigencies of the work require it. In some cases, it may be permissible to bevel both edges. A combination similar to those shown in Fig. 19 may then be used. Other situations may arise where no beveling at all can be permitted. Here one must bear very distinctly in mind that fusion over the whole face of each edge is the object sought. An arrangement such as that shown in Fig. 20 will sometimes enable the operator to meet this requirement, especially if he works from both sides. A crevice of some width may often be bridged by the skilful workman building out from both faces.

A wire or similar strip of metal may be used to close the crevice, if the operator subsequently works from the other side and makes sure of completely fusing the wire into the weld. See Fig. 21. The material of this wire should of course be suitable for in-

Fig. 14

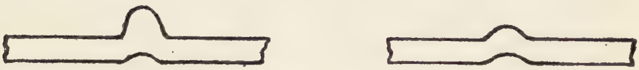


Fig. 15

Fig. 16

Fig. 17

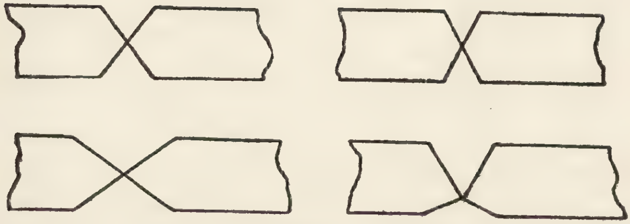


Fig. 18

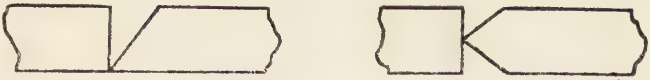


Fig. 19

Fig. 20

Fig. 21

Fig. 22

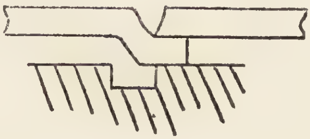


Fig. 23

Fig. 24

Fig. 26

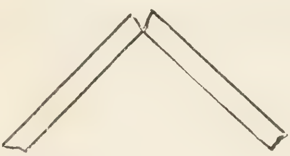


Fig. 25

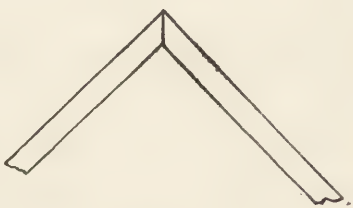


Fig. 27

corporation. In some cases, it may seem preferable to use a wire at half the depth of the groove. Such an arrangement is shown in Fig. 22. These auxiliary pieces must be thoroughly incorporated into the final weld. The operator should permit no uncertainty to hang over this matter. A piece of the welding wire itself may sometimes be used, if its diameter is sufficient; or, obviously, a piece of wire of precisely the same material. These suggestions must not be taken as license to fill the groove with two or three varieties of metal. The safe general rule to follow is to put into the weld but one kind of material. This material should be precisely the same as that of the work, unless there is a reasonable certainty that the use of a different welding material will produce at least as good results.

If sheets can be welded on a suitable table and with the aid of clamping pieces arranged to parallel the joint, this will be the procedure to select. See under the heading *Butt Welding by Hand without Wire*. Of course, there are many cases, where the welding has to be done without these arrangements. The intelligent welder will, however, seek to replace them as far as possible. If similar clamping can be managed, let it be done. The operator should remember to make due allowance for the effects of contraction of the freshly made weld by widening the gap on the side away from the point of beginning in the case of long joints.

A useful type of joint is shown in Fig. 23. Here one edge is so bent that there is provided a recess for the reception of the other edge. If the bend is properly made and the plain edge suitably beveled, a

groove will be formed when the two edges are placed in position. If the joint to be made is a long one, it will be important that the two sheets be securely clamped in position. The groove is utilized for the reception of melted welding material. Beneath the position of the joint, a groove should be provided in the support or table on which the work is clamped. This groove is for the purpose of avoiding loss of heat by conduction. It will ordinarily not be necessary that this groove be filled with mica or asbestos, for the reason that usually it will be possible to arrange for the clamping to one side of the groove. The far ends of the sheets should be so arranged that the groove between the sheets which is to be filled with new metal is somewhat wider than on the near side. However, if the clamping is provided along the entire length of the joint and is sufficiently powerful, the widening may be made inconsiderable. Thus, a joint nine feet long has been made in practice with an allowance of only 1/4-inch of spread at the far ends, the thickness of the metal in this case being 20-gauge. By the use of a suitable but simple device for clamping and unclamping, a seam of this character has been made in 13 minutes; length of seam 9 feet, thickness of metal 20-gauge.

Welds may be made thicker than the sheets, if desired. The object sought in this is a strengthening of the joint. This thickening may be carried out on both sides. In fact, the added material may be made to overflow onto the general surfaces of the sheets. In such cases, the operator must see to it that proper attachment with these surfaces is secured. This is accomplished by fusing them wherever contact with the new material is desired.

Angular Joints

The procedures illustrated in the preceding sections will be suggestive of methods applicable when the sheets to be united are at an angle to each other. They should be studied in detail with the object of applying them when possible to angular conditions. In Fig. 24 we have an example of a right-angle joint. In the case of thin material, this joint may be made without the use of a wire. The torch should be directed to bisect the angle of the groove. Under these conditions the working flame will operate equally on both edges without the necessity of especial attention. This is a useful form of weld. By suitably forming the edges, material may be supplied for the groove. But a very good weld can be made with thin material without any forming of the edges. It will be weaker than the sheet, of course. By means of a very simple beveling, the size of the groove can be very considerably decreased without making it impossible or even difficult to secure heat penetration. This possibility is illustrated in Fig. 25. A variation of the angular joint without prepared edges is shown in Fig. 28. In cases where there seems to be advantage, the welding wire can be used to supplement the supply furnished in the foregoing examples by the corners of the sheets.

Double welding can be applied to these joints. The form shown in Fig. 26 would perhaps be benefited by applying the working flame to the inside of the angle subsequently to the exterior operation. Of course, a wire may be used, if there appears to be advantage in doing so. Further, by upsetting or otherwise thickening the edges and suitably forming them, additional material may be supplied. This will ordinarily be preferable to the procedure with the wire.

The joint may be a mitred one, if the sheets are not too thick. See Fig. 27. If this arrangement seems to produce too much material on the outside and too little on the inside, we may use a form of joint of the type shown in Fig. 28. Weld on both sides in both these cases. By simply displacing the sheets of an ordinary mitred joint in the way shown in Fig. 29, we shall in effect distribute the material partly to the

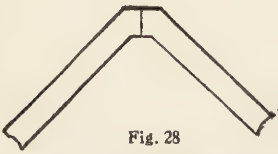


Fig. 28

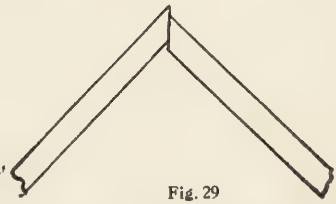


Fig. 29

outside and partly to the inside. This joint should be welded on both sides.

There are many cases where the question as to whether the finished joint is of the full strength of the flat sheet does not enter in any important way. If the joint must be of nearly full strength, then measures should be taken to make it so. In the section on *Restoration of Steel,* methods of restoring overheated steel are given. These should usually be applied unless there are prohibitive reasons, whether other measures are taken or not. That is to say, always anneal, if possible. Again, the weld may be thickened as already explained. This may, if desired, be carried out on both sides.

Attention may here be directed to the fact that by a judicious placing or forming of the joint it may be relieved of unusual stress and strain. This matter is treated at some length in the chapter on *Tanks, etc.*

CHAPTER VI

Tanks, Retorts, Etc.

IN constructing vessels of sheet metal which are to be subject to alternations of higher and lower pressures from the interior, it is ordinarily advisable to use a special form of joint at any corners or to avoid corner joints altogether. Consider a tank, for example, which has vertical planes for its side walls and a rectangle for its plan. If such a vessel is subjected to internal pressure, the horizontal sections will everywhere tend to become circles. The reason underlying this tendency is the geometrical principle that a bounding line will inclose the greatest area when it is in the form of the circumference of a circle. Suppose the tank to be filled with water under pressure. The effect of the pressure is to make the tank seek to hold as much water as possible. The horizontal sections will consequently seek to become circles. This will result in the angles of the sections seeking to become larger. See Fig. 1. Here we have such a corner. The arrows indicate the movements of the sides. These movements will produce a tensile or stretching strain at A, and a compressive or crushing strain at B. Every time the tank is subjected to an internal pressure following a period of no pressure or less pressure we shall have this combination of com-

pression and tension. It is not difficult, perhaps, to see that repetitions of these effects may result in severe testing of the metal at the corner. If the corner is rounded, the effects will be reduced. If the corners are so rounded out that the whole horizontal section becomes a circle, then there will be a complete elimination.

If a welded joint be made in the usual manner at a square corner like that of Fig. 1, we shall be locating the weld at the point of severest trial. This may be all

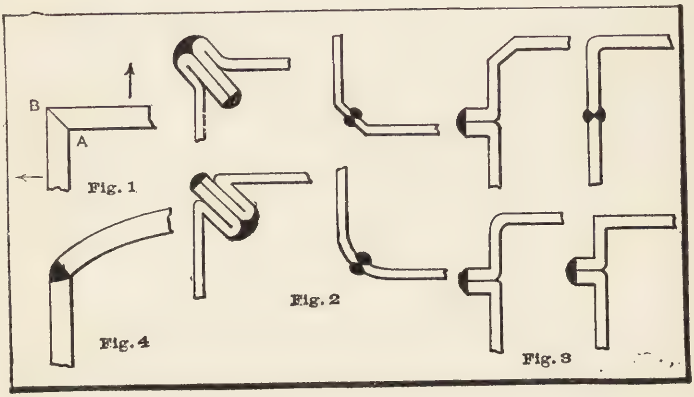


Fig. 1 Fig. 2 Fig. 3 Fig. 4

right, but the fact should be borne in mind. By forming the joint in the various ways shown in Fig. 2, the weld may be strengthened or largely if not entirely relieved.

It would be as well or better, however, to remove the joint from the corner altogether. We have in Fig. 3 representations of such forms. These are not to be regarded as by any means all the possible ones.

Further, it is probably better yet to remove the joint to a location midway between corners, if conditions permit. The best thing of all is to change the horizontal section to a circle. In all cases, there will be latitude in the selection of the particular form of joint. Quite a variety of joints are shown in the chapter on *Sheet Metal Welding.*

Since a given area of bounding surface will contain the greatest volume when in the form of a spherical shell, we are prepared to understand that any corners in a vessel of any form whose walls are subjected to pressures from within outward will experience the combination of compressive and tensile strains whenever the pressure is resumed or increased. It will be important to consider this matter in connection with the welding on of bottoms and tops of cylindrical and similar tanks, if the question of pressure has any real significance. This subject is treated under the head of *Tops and Bottoms of Sheet Metal Vessels,* page 75.

Household Utensils

The usual forms of certain household utensils—such, for example, as coffee and tea pots—occasion considerable difficulties in manufacture. This is particularly the case in connection with the attachment of the spout to the vessel. Soldering has been much used in making these joints. However, the basic material of the solder would ordinarily be different from the material united. As the uses to which the vessels are put expose the joints to the action of acids, we have the result that galvanic currents are set up. These would operate in the direction of injuring the

joint. Vessels made of aluminum are especially exposed to the action of such currents, for the reason that this metal is electropositive to pretty much all the common metals. It seems that an effort was made to obviate the difficulty in the following way. At the hole in the body corresponding to the spout, the metal would be bent inwards. The material of both body and spout would then be bent into a fold on the interior. No soldering material need be used. It has been pointed out, however, that the presence of this fold upon the inside is very objectionable. Even though there is a close seam when manufacture is complete, still the effect of heated tea or coffee is liable to open it somewhat. The crevice then becomes a trap to catch little particles. Further, it is thought that such crevices become the home of bacilli, leading to the corrosion of the metal. Oxy-acetylene welding is a solution of the foregoing difficulties.

However, when seeking to unite spout and body by means of the oxy-acetylene torch, we are confronted with several difficulties, especially if the sheet metal be aluminum. These difficulties can be overcome, so that the oxy-acetylene process remains a practical solution. The expansion and contraction of aluminum under thermal changes proceed very rapidly, so that one has to be on his guard against distortions of the work. The melting point is low, so that with thin metal holes are apt to result. Heated aluminum is very readily oxidized, with the result that a proper intermingling of the material is difficult to get apart from special provisions. In view of these facts, it is recommended that, unless other requirements intervene, the joint be arranged off of the main body;

that welding wire be dispensed with; and that a suitable flux be employed. In Fig. 4, we have a joint so arranged as to eliminate the necessity for the welding wire. The spout fits closely into the hole. It is introduced far enough to protrude into the interior, say, 1/8 inch. This projection furnishes the welding material. The great advantage is that mind and hand are relieved of the management of a wire. Another ad-

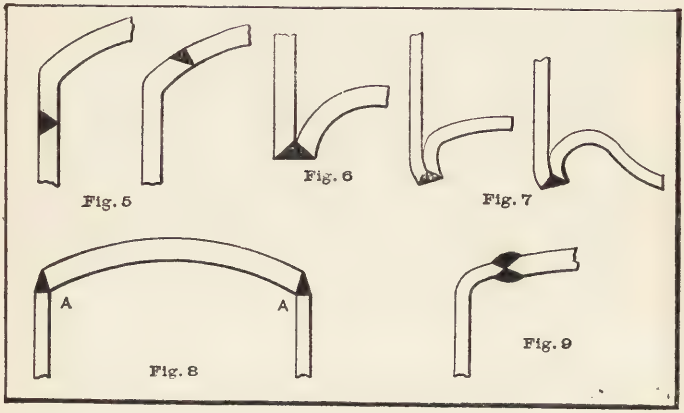


Fig. 5 Fig. 6 Fig. 7 Fig. 8 Fig. 9

vantage consists of the fact that the welding material is precisely the same as the material of the work. There is some disadvantage in operating on the interior; but this is much reduced by using a tip of special form. The appearance on the exterior is good, as no added material is located there. Another form of joint is shown in Fig. 5. Here the diameter of the hole is at first made smaller than the interior diameter of the lower end of the spout. The material

is then bent outwards to form a kind of ridge of precisely the same interior and exterior diameters as those of the spout end. The body and spout could now be butt welded together by using welding wire. It is preferable, however, to bend outwards the edge of the ridge and thus supply the needed metal in a convenient fixed position. If it seems more desirable, the auxiliary metal may be arranged in connection with the spout. That is to say, the edge of the spout is bent outwards instead of that of the ridge on the body. This form of joint is shown in Fig. 6. In either case, the ring of metal protruding at the joint will not be thick in a radial direction—say, ⅛ inch. In both forms of joint, we have a smooth interior and a weld of the same material as the work. The latter form has two especial advantages: the welding is done from the outside, and the joint is somewhat removed from the body.

Tops and Bottoms of Sheet Metal Vessels

One of the most important applications of oxy-acetylene welding is in connection with the manufacture of tanks, cylinders and the like from sheet metal. In this field, the new process promises to supersede soldering and riveting to a very large extent. The advantage over soldering consists principally in the increased strength of the joint and the equality of the expansion and contraction of the metal in the seam and in the work. There is much less likelihood of the occurrence of poisonous corrosions. The art is being practiced abroad and also in the United States. One of the problems consists in the welding on of

the tops and bottoms of cylinder-like bodies. It seems that one of the first methods employed was by making a joint of the type shown in Fig. 7. The welding could be done from the outside and could be well finished. However, when the vessel was subjected to pressures from within, it seems that both compressive and tensional stresses would occur, with the result that cracks would come into existence. One can see that any change of shape increasing the obtuseness of the angle at the weld would produce compression. Two solutions of the difficulty may be found illustrated in Fig. 8. The idea is to eliminate compression and reduce all strains to tensions. This result would seem to be pretty well accomplished by either method. It will be understood that where the metal is quite thin, sufficient surface of contact can be secured by bending the metal out to form a kind of flange. Or, by using more welding material than necessary to give a joint flush with the adjoining surfaces, a stronger weld can be made. In all these cases, the top or bottom is convex on the exterior.

Another method is to concave the piece. Such forms are especially suitable for bottoms. See Fig. 9. Here the bottom is not only concaved, but the rim is bent rather sharply to conform to the wall of the cylinder. The edges of bottom and cylinder are both suitably beveled to provide a welding groove. Another method, though not necessarily including concaving, is to bend up the rim a short distance, the dimensions of the piece being such that this rim snugly envelops the cylinder. The two may then be welded together.

The use of flat tops and bottoms is by all means to

be avoided. The expansion and contraction of these during welding are different from those of the cylinder. A perfectly flat piece is unsuited to yield to the cylinder, the result being that the work is liable to distortion. The convexing and concaving of tops and bottoms seem to provide a suitable margin for give and take. Two other forms of bottom are shown in Fig. 10. In both, an elasticity in diameter is provided for. The bending in of the edges enables the

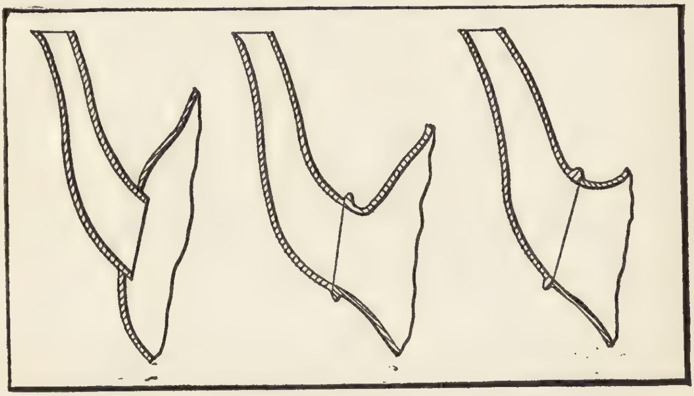


Fig. 10 Fig. 11 Fig. 12

cylinder to assist in the support of the bottom when the latter is under pressure of gravitation. In some cases, it may be necessary to prevent the cylinder from diametral expansion when welding. A heavy removable band of metal in the form of a hoop may be used for this purpose. It will be placed close up to the location of the seam. Much of the heat from the cylinder will be absorbed and dissipated by it.

An interesting example of the application of one or more of the foregoing principles is afforded by a large containing vessel constructed by Munk & Schmitz, Cöln-Bayenthal, Germany. This vessel is a cylindrical shell, closed top and bottom. It is formed of sheets. These are 0.40 inch thick in the cylindrical portion, and 0.83 on the end portions. The huge vessel is 15 feet high and over 9 feet in diameter. All joints were made by the oxy-acetylene torch. It has been tested successfully with a pressure of about 90 pounds per square inch.

If the joining of the top, say, to the cylindrical shell had been made at the precise point where, geometrically, the side wall joins the top, as shown in Fig. 11, then an outward pressure exerted from within would tend to produce a spherical form, for the reason that a surface of given area will contain the maximum volume when that surface is spherical. This would mean the widening out of the Angles A.A. There would result a tensional stress on the inner portion of the weld and a compressive stress on the exterior. With numerous fluctuations of the pressure, we should have reason to expect the formation of cracks. The method disclosed in the upper part of Fig. 8 might have been adopted here. Instead, however, the weld was displaced in the other direction and located a little within the periphery of the geometrical top. In forming such a weld, one must not forget the effects of expansion and contraction. It is recommended that hammering of the weld be carried on during the cooling off process. The hammering should be stopped when the metal is still pretty hot. If a horseshoe magnet still attracts it, the heat is perhaps a little too low. Further, sub-

sequent to cooling, the region involved in high temperature should be well annealed. This may be done, in this case, by using two torches—as, for example, two oil torches—for the gradual re-heating. One should operate from the inside; the other, from the outside. In performing the welding operation also, it is advisable to operate with two welding torches, one within and one without. The weld will be of the double V character, as shown in Fig. 12. The bottom of such a vessel should be so arranged that the weld will not be located where the weight of the vessel itself will come upon it.

An Important Practical Example

In Fig. 13 is shown the method of making joints between a cylindrical shell on one hand and the top and bottom on the other, used by the Vilter Manufacturing Co., Milwaukee, Wis. It will be noted that the top is convex and the bottom concave, as viewed from the outside. The shell is of 3/8-inch boiler iron. The metal in the heads is 1/2 inch thick. The tank is 20 inches in diameter and 24 inches in length. Both heads are flanged so as to fit inside the shell, as shown in the view. A hydraulic test of 1,200 pounds per square inch was given to a drum of this description. A hole was drilled on one side of the shell and a suitable nipple inserted after tapping. Connection with a hydraulic press pump was made and pumping begun. At 1,100 pounds pressure, the nipple started to leak. But no leaks, small or large, were disclosed at the welded joints. A No. 7 tip (Davis-Bournonville) was employed in making the straight weld in the shell of such a drum; on the ends, a No. 8 tip was

used. The straight weld was made in 45 minutes at a cost of about $1.62 (exclusive of labor, but including depreciation); the circular weld at the convex end occupied 2.67 hours at an expense of about $6.99; and the circular weld at the concave end required 2 hours at an expense of about $5.24. At 30 cents per

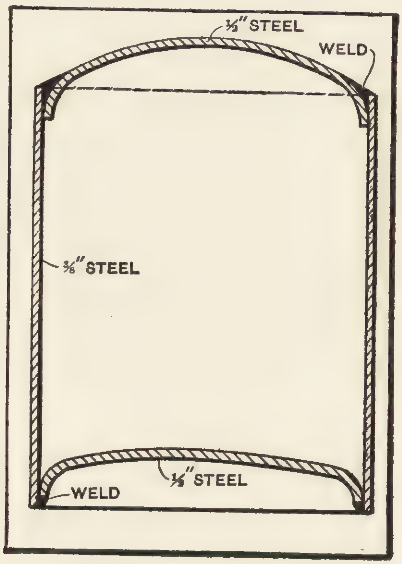


Fig. 13

hour, the labor cost would amount to about $1.63, making the total $14.03. If we add 7 per cent. for supervision, etc., we have a grand total of about $15.00. These tanks are used at a maximum working pressure of 300 pounds per square inch. A water cooled torch was employed in part of this work.

CHAPTER VII

Welding as a Caulking Process

OXY-ACETYLENE welding is being employed as a means of making perfectly tight a joint which has been made by other means. That is to say, it is being used as a caulking process. Indeed, this promises to be one of its important applications. For example, steel pipe with riveted seams is being applied to the purpose of conducting water under the pressure of a very considerable head. The question of securing an absolutely tight joint is very important. At present, the oxy-acetylene process is not in competition with riveting as a means of making the joints themselves. But it is a method of making the riveted joint a tight one. Again, the seams in the roof of some of the very finest of steel passenger railway coaches depend upon rivetting and a supporting bar for their strength. But they are made weather-proof by oxy-acetylene welding. Quite possibly, riveting might be dispensed with and welding alone relied on for the strength of this joint. With that question, I am not now dealing. In such cases as the foregoing and in many others, oxy-acetylene welding is an admissible means of caulking.

Soldering and brazing are also methods of securing tightness of joints, but they are at times difficult

of application or unsatisfactory in results. Oxy-acetylene welding permits the use of precisely the same material as that in the work. This is important for more than one reason. For example, where the finished joint will be subjected when in service to considerable fluctuations of temperature, it may be of great importance that the *expansions and contractions* with the new material shall occur in the same degree as with the old material of the work itself. In general, metals expand and contract at rates which vary with the material. But acetylene welding permits the use of a welding rod of the very same metal. Secondly, when diverse materials are involved, we have the bad results consequent upon the setting up of *electrolytic currents* in cases where liquids containing acids in solution come in contact with the seam. The joint may suffer deterioration with the result that leakage is caused. Thirdly, oxy-acetylene welding permits a *strong closure* to be made. This is not always the case with soldering. In oxy-acetylene welding, a joint may be effected where the strength is a high percentage of the strength of the work itself, even though no difficult annealing operations are carried out.

Oxy-acetylene caulking can be done in the shop or in the field. It can be done prior to final assembling or subsequently. There are exceptional situations, but these are the facts for the bulk of the ordinary cases. Moreover, *oxy-acetylene caulking* is an economical proposition. It is not ridiculously cheap; but, considering the quality of the work, it is economical. For example, the caulking of the roofs of the steel passenger coaches referred to cost the concern build-

Welding transverse seam on lower deck of steel railway car

ing these cars 4 cents per lineal foot for the labor. They estimate the gas expense at about 1½ cents, so that we have a total of 5½ cents per foot. The material was steel sheeting about $\frac{1}{16}$ or $\frac{3}{32}$ inch in thickness. On each car, a total of about 232 lineal feet of roof joints was made or sealed by the oxy-acetylene process.

As an illustration of what may be done *in the field,* the work done on the Boulder pipe line of the Central Colorado Power Co. may be cited. This line is located near Boulder, Col. Altogether, it is about 9,000 feet in length and has a total drop of 1,875 feet. Now a hydraulic head of 1,875 feet produces a pressure of 814 pounds per square inch, if we disregard frictional considerations. It will be seen that the lower portion of the line would be under severe pressure conditions. At the base, the pipe line diverges into two branches which serve two 10,500 horse-power water wheels. These are of the impulse type and drive two 5,000 kilowatt-hour generators. At the top, the pipe is 4 feet 6 inches in diameter. At the bottom the diameter diminishes to 3 feet 10 inches. It is constructed throughout of sheet steel. The wall thickness varies from ¼ inch at the top to 1¾ inches at the base.

Especial interest attaches to the lower portion of the line, because of what took place subsequent to the beginning of actual service. The pipe was shop-assembled into 21-foot sections. Each section consisted of three rings. The joints were made by bringing the edges of the wall together and riveting cover straps in place. There was a single longitudinal joint extending the length of the section. These joints

had wide cover straps within the pipe and narrower ones on the outside. The exterior cover strap of each section was a single piece. Four lines of rivets—two lines to each side of the joint—held three thicknesses of metal together. The interior strap was held to the wall by two additional lines of rivets, one to each side of the outer strap. The circular joints were secured by girth straps also riveted in place. In the field, it was necessary to make girth joints and connect up longitudinal straps. The top longitudinal strap fell short of the pipe section at one end and overhung it at the other. When the field connections were completed, the joints of the external strap came before or behind the center line of the corresponding girth straps. The amount invested in the 1.7 miles of pipe line was about a quarter million dollars, exclusive of the investment in excavation of trenches, the anchorages, etc.

In August, 1910, this line was put into service. It was not long, however, until leaks began to develop. The caulking of the field joints where the 21-foot sections joined each other was ineffective in resisting the tremendous pressures. The water escaping with great force threatened to extend the damage by the action of the sand in the vicinity. This sand would be caught up by the water jets and projected onto the rivets. In other words, wet sand blasts were in operation upon a vital part of the work. No effective method was known of stopping these leaks; so in November the line was put out of service. The problem then was to find a way of effectively sealing about 200 field joints, 27 of which were in rock tunnel construction. After considerable investigation,

the decision was reached to deal with the leaks by means of oxy-acetylene welding.

The problem was to seal the joints of the 21-foot sections of longitudinal strap and thus unite it into one continuous cover plate 4,000 feet long; and also to seal the joints where the girth straps connecting sections joined the longitudinal strap. There would be two such joints to every section. When completed, we should have a kind of backbone and ribs three-quarters of a mile long, the whole consisting of a single piece of steel.

It was imperative to get at the work at once and carry it on during the winter. Otherwise, the loss would be greatly increased. In addition to the difficulty involved in the severity of the weather conditions, the location of the work on a steep mountain side at a distance from the town was calculated to produce problems in connection with the delivery of acetylene and oxygen at the point of use. A portable shanty was set up and moved from point to point. This afforded shelter to the men actually engaged on the welding operations. The acetylene was manufactured at a selected point and then piped to the spot where operations were being carried on. Acetylene was piped as far as 500 feet from the location of the acetylene generating plant. In the course of the work covering a total distance of 4,000 feet, this plant was moved four or five times. The oxygen plant was set up at a separated point. It consisted of generating apparatus and a compressor. The gas would be compressed into cylinders and then transported to the point of use on a construction tramway or by means of a stone-boat drawn by a horse. Al-

together, 18 tons of calcium carbide were consumed in the manufacture of the acetylene, and 23 tons of chlorate of potash in that of the oxygen. From these facts we can get an idea of the extent of the caulking operations. In order to prevent freezing of the water employed in the generators, it was necessary to provide a means of supplying heat. A steam heating apparatus was used for this purpose.

Three welds had to be made every 21 feet. Altogether, the lineal length of a set of three amounted to a length varying from 30 to 50 inches. We readily calculate, then, that a total length of welding was done amounting to about 8,000 inches, or 667 feet. This work was nearly completed in March, 1911. It was performed by one expert welder and 4 or 5 men trained by him. The thickness of the straps united ranged up to 1¾ inches. In addition to the bare unions along the lines of contact of strap with strap, it was thought well to add new metal and make fillets where the girth straps joined the longitudinal strap at right angles. Altogether, we calculate that 800 such filled in connections were made. The whole work, with the exception of some less important welds, was done by the few men in about 3½ months. The general manager of the Central Colorado Power Co., at the time when the work was thus about completed, expressed himself as follows: "The Company is highly satisfied with the work and feels that without this process of welding it would probably have been necessary to replace 4,000 feet of the heaviest portion of the pipe."

CHAPTER VIII

Boiler Work

THE application of the oxy-acetylene torch to the repair of boilers is a highly advantageous one. There are many cases of such character that if the method can be used the economical advantages will be very great indeed. Boiler repairs under the older methods were not always expensive so much because of the cost of the actual work of the repair operation as because of the expense of dismantling and other auxiliary operations. Often, too, the expense would be much increased because of the stoppage of machinery dependent upon the boiler. The very advantages, however, are apt to tempt the too enthusiastic oxy-acetylene operator to undertake repairs scarcely practicable in the present state of the art. But there are many opportunities where the welder will not be going beyond what has already been done.

In fire tube boilers, the tubes terminate in plates of metal. In certain material used for these plates, the boring of the holes sets up an alteration in the structure to a certain depth. As the holes are pretty closely spaced, it will be seen that the alternations of temperature will be operative where the material is thus much reduced in cross-section. We should expect

then that the expansions and contractions here would be very considerable. This fact combined with the deterioration due to boring will explain, in part perhaps, why so many leaks develop where tubes and plate join. Leakage once begun, corrosion sets in and occasions, unless checked, a serious want of tightness. The corrosion may be confined to the water side, but it is frequently operative on both sides. Further, the plates often develop a more or less cracked condition in the portions between the holes. These are due, in

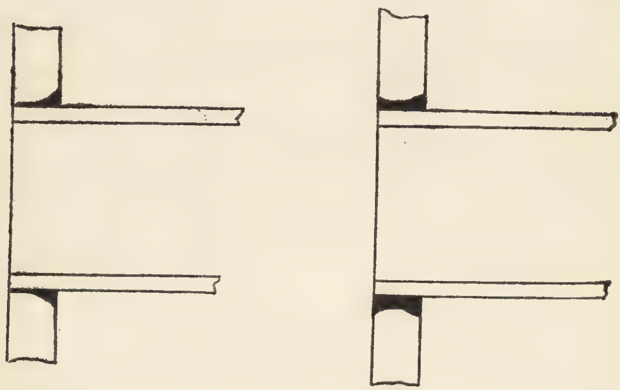
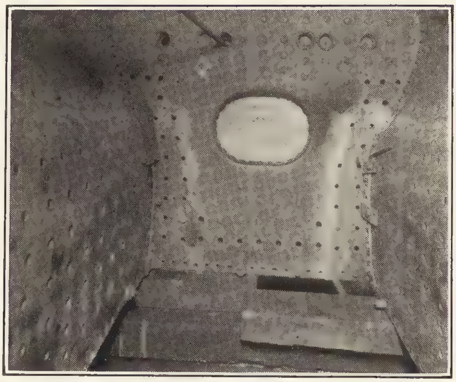


Fig. 1

part no doubt, to the effects of expansion and contraction.

To deal with the conditions now outlined, the metal involved must be thoroughly cleaned. No particle of corroded metal, scale or other foreign matter must be allowed to be present. In welding up the cavities in a tube plate around a tube, if a current of air is allowed



Fire box welds. Two long welds in fire door sheet. These welds are continued on the two side sheets

to pass through the tube, the cooling effect may be disadvantageous. Such a current should ordinarily be prevented, as by stopping up the tube at one end.

Consider now the tube plate. If a crack be operated upon, it should be cleaned out so thoroughly that no possibility of the presence of anything else than sound metal exists. A preliminary heating may now be given. This is partly for the purpose of enabling the crack to be opened up. In order to make it do so advantageously, a cooling stream of water or air may be played on each side of the crack. The differential contraction thus brought about will tend to throw the crack open. The object of expanding the crack is to take care of the contraction in the weld after the completion of the work. When the crack has opened, a wedge may be put in to keep it so. The welding may then be started from the side opposite to the wedge. It is said to be of advantage to limit the region of heat by using a water spray or an air jet. This means of cooling may have its effects directed to reducing the temperature outside of the general region of the operation. If the number of cracks is considerable, it will probably be better to cut out the portion involved and then weld in a new piece.

Under some circumstances, it may seem best to combine riveting and welding. The tube sheets of the steamer *Sinai* of the *Compagnie des Messageries Maritimes* were about 1 inch thick. Riveting was employed above and below in putting in the section. On the sides, however, the joints were made by welding. In such a case the riveting will follow the welding. Otherwise the expansions and contractions induced by the

localized heating might shear the rivets. The boiler first dealt with was subjected to a test pressure of 1.5 times the operating pressure. No want of tightness developed. After a voyage, during which the repaired boiler was put into service, no imperfection could be discovered. All six of the boilers were then dealt with in the same way.

The restoration of corroded localities is very important in boiler repair. Attention has already been

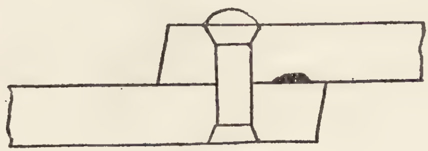


Fig. 2

directed to the method of dealing with the corrosions occurring at the joint between tube and tube plate. Sometimes a corroded place will be located between two plates riveted together. See Fig. 2. The first thing is to get access to the defective spot. It must then be most thoroughly cleaned. The filling up will be a comparatively simple matter. The locality which has been highly heated should be given an annealing treatment with the outer flame of the torch. In getting access to the corrosion, it may be simplest to cut away the overlying metal of the other plate. New material will be added on after the corrosion has been dealt with. Ordinarily, it may be best in adding this new metal to avoid welding it on to the other plate as well as to the one to which it is desired to add it. It has proven best to remove the rivets before beginning, as

the expansion and contraction may otherwise put them under severe transverse strains. In internally fired boilers, a location of frequent corrosion is in the flue running through the boiler along a line a little above the fire grate. This strip of corrosion may be a number of inches wide. As in similar cases, there must be a thorough cleaning away of everything interfering with the exposure of clean, sound metal. Our problem then is simply to build up, layer by layer, the region affected. It is usually wisest to add metal that is identical with that to which it is added. At times, it may be a little difficult to match the material. The weld should, of course, be annealed.

A location of frequent corrosion is at the bottom of the back plate of internally fired boilers. A repair dealing with such a defective place has occurred, to mention an instance, with the steamship *Marsa*. An external corrosion of the front plate may occur from leakage, the effect of bilge water, or the action of wet ashes. The joints of man-holes and mud-holes often become leaky. Corrosion is apt to follow. Often such defects can be dealt with by cleaning away all defective metal and welding on new. It may be necessary, however, in some cases to add a new piece. The joint may be made tight by welding on metal as indicated by the black portions shown in Fig. 3. In all cases where steel plates have been welded, annealing should be carefully done. The outer flame is a very convenient thing to use. Its temperature is moderate and it has some size. However, other methods may be employed. The object is to gradually heat up to the annealing point all the material that has been involved in the high temperature.

The annealing process for such steel as would be used in boiler plates (that is, steel of less than 0.40 per cent. carbon) is roughly as follows: It must first be allowed to cool below 1,275 degrees Fahrenheit. It may then be gradually—very gradually—heated up again to a temperature ranging from 1,470 degrees up to 1,650 degrees. The variation of 180 degrees corresponds with the variation in the carbon content. The more carbon, the less the temperature at which the annealing should finish. If the carbon content is 0.30

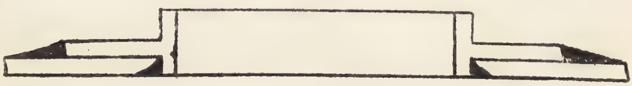


Fig. 3

per cent., then the annealing temperature should be about 1,515 degrees. The temperatures here given are not to be regarded as absolutely exact. They will serve, however, for a practical guide. If the welding, together with the annealing has been carried out perfectly, we may look for something near the original strength of the metal. Ordinarily, however, these operations will not be thus carried out; so that a liberal allowance should be made when estimating the strength of the metal after welding because of the probable imperfections necessarily incident to boiler repair work. The annealing should never be omitted. It should extend to all portions at all involved in high temperature, especially when nearing the final temperature of re-heating. It should be carried out very gradually. One great advantage of re-heating slowly is that then we may be fairly sure that all the material

—that within as well as that without—has been reached. The interior structure which has been overheated and weakened by the high temperature of the welding operations will not be restored unless it is actually re-heated. It is absolutely necessary therefore that the inside as well as the outside of the metallic mass should be raised to the required annealing temperature. It must be properly cooled, and properly reheated. It would be best, no doubt, if the re-heating could be accomplished steadily and everywhere simultaneously. That is to say, there should not be draughts and the heating flame should preferably not be moved away from a given point for more than a moment at a time.

It might be thought extremely difficult to determine the annealing temperatures. There is, however, a very simple method of determining the temperature of 1,400 degrees for steels having less than 0.40 per cent. carbon. Above this temperature, such steels are not appreciably attracted by a magnet. A five or ten-cent magnet will be of considerable service, therefore; the excess of temperature above 1,400 degrees may be determined by the judgment assisted by practice. It is perhaps better to err on the side of getting a temperature slightly too high. It is important also—so it would seem—to cool the work off by slow degrees. With this purpose in view, we keep the annealing flame playing for awhile after the maximum temperature has been reached, but allow cooling to go on. Asbestos cloth will at times be serviceable in retarding the cooling. At other times, it may be possible to pack the parts for a considerable area around with some poor conductor of heat as sand, ashes, slaked lime.

There are situations in boiler repair work such that heating may be done from both sides at once. It will often be of assistance in the welding operation proper to have the assistance of heat from the other side of the plate. Further, annealing should be managed from both sides where possible.

Boiler work often calls for the workman to get into a more or less contracted place. He should have the assistance of an associate. It is a good rule to require the men to work in pairs. In any emergency, there is another man at hand.

A Notable Boiler Repair

In some internally fired boilers, the horizontal flues are provided with annular corrugations which serve to increase the strength and provide a larger heating service. The fire plays against the upper interior surface, while the lower portion lies in water comparatively cool. It thus comes about that the upper surface is much more subject to corrosion. A flange arranged on the inner end provides a means of attaching the corrugated flue to the wall of the fire box by means of rivets, the flange being within the fire box. A rather novel method of dealing with the corrosions of the upper portion originated, it would seem, with a Belgium concern.

The corrugations do not extend quite the whole length of the flue, but terminate on the inward end a short distance from the flange before mentioned. This plain portion of the flue is but little exposed to the direct action of the flames. They swing, as it were, below it, being directed by the last corrugation.

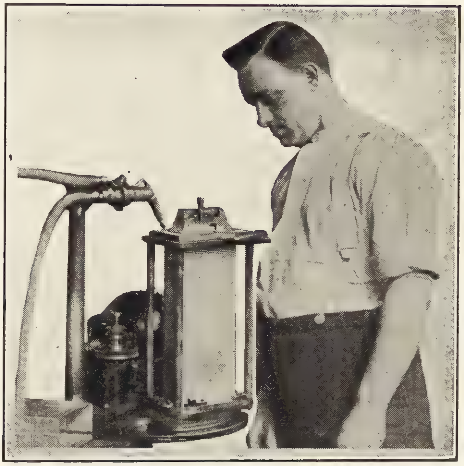
In this region, the flue was cut in two by means of an oxygen jet used with a heating torch. Before cutting the rivets securing the front end of the flue were removed. It was now possible to withdraw from the boiler the whole flue except the far end. The corroded places were then dealt with. The repaired flue was returned to its original position, except that the good under portion was now placed uppermost. The joint with the portion left in was made good by means of the welding torch. This position, as has already been pointed out, is a comparatively sheltered one in so far as the flames are concerned. The riveting of the forward part on to the front plate again was, presumably accomplished by filling up the old holes and the boring of new ones. The same Belgian concern has performed many repairs of this character.

CHAPTER IX

Machine Welding

IN welding by hand a number of difficulties operate as a bar to certain lines of commercial work. For example, in seeking to unite very thin sheets by means of an ordinary butt joint, the hand of the operator can not be depended upon to give precisely the right speed to the torch as it is carried over the seam. If the flame is given too rapid a movement, the weld is either not made at all or it is imperfectly done. If the movement is too slow, the work will be burnt away, so that patching becomes necessary. Further, the operator may vary the vertical position of the flame. This will introduce a new complication, since this irregularity will result in a fluctuation in the amount of heat supplied. To get the best results in the minimum time it is best to maintain the torch at a constant angle, to maintain its position vertically and transversely in a fixed nearness to the joint, and to move forward at a precise rate of speed. These requirements can not be met at the best commercial rate of speed by means of the hand of the operator. They can be met by means of specially designed machines.

These divide themselves into two classes: those where the work is fixed and the torch is moved; and those where the work is carried beneath a fixed torch.



Machine for welding tops and bottoms

Steel containers. Edison Storage Battery Co.

For some work the choice of method is a matter of indifference; for other work, it may be imposed by the conditions.

A very recent machine is one designed and built by the Davis-Bournonville Co. of New York City. The same machine may be used for the cutting of steel. The torch is here given the movement, and the work remains fixed. There is a substantial vertical post of perhaps six or seven feet in height. A kind of sliding sleeve envelops this post. As this sleeve is provided with a pinion and the post with a rack, the vertical position of the sleeve can be readily controlled by the operator. On the side of the sleeve diametrically opposite to the pinion there is a projecting bracket in which is arranged one end of a hollow cylindrical arm. This arm extends horizontally for six or seven feet. A brace extends from the upper part of a kind of collar arranged on the outer end of the arm to a point at the upper end of the sleeve on the vertical post. In the hollow of the horizontal arm a shaft is arranged which is provided with a bevel gear on the end next the post. A second bevel gear is horizontally arranged to mesh with the first. The second one is driven by a vertical shaft which passes through it. The gear slides vertically on the shaft, which remains in a fixed position. When the sleeve on the post is raised or lowered, the vertical shaft is still competent to effect the drive of the horizontal shaft in the arm. A screw is rotatably arranged in a horizontal position just above this arm. By means of a change-gear arrangement at the outer end of the arm, the screw may be driven at speeds having a variety of ratios to the speed of the vertical shaft. The speed is always reduced, however. At the

base of this shaft a horizontal friction disk is arranged. This is driven by a friction pinion mounted on a short horizontal shaft. On the outer end of this shaft are a tight and a loose pulley. The friction pinion may be moved towards or from the center of the disk. It will be seen from these arrangements that a range of speeds can be transmitted from the countershaft to the vertical shaft. Each of these speeds may be reduced in accordance with a set of fixed ratios determined by the gears on the outer end of the arm. The result is that, for every speed of the vertical shaft, we shall have several speeds of the screw. The screw has six threads per inch and controls a carriage which slides on the horizontal arm. The carriage is provided with a holding device in which the torch is removably secured. The angle of the torch can be adjusted, and also the vertical position of the tip. The carriage can be readily released from the control of the screw and a quick advance or return made.

We have thus a power driven mechanism competent to give a very uniform motion to the torch at any one of a considerable range of speeds. The angle of the torch is maintained and also the movement in a straight line. Vertical adjustment of the arm to accommodate the conditions of the work is easily obtained by the operator.

Pretty much any and every kind of sheet welding can be done by this machine where the joint is accessible, straight, and does not require a circular movement of the torch in addition to the forward motion in order to cover a wide track. There is a considerable range of work which falls within the limitations stated. Once the forward speed for a given line of work has

been determined, welding may be done by comparatively unskilled labor with uniformity and precision. For example, it may be ascertained that a forward speed of 10 inches per minute is the precise rate suited to the welding of a certain type of joint made by the edges of a given thickness of sheet steel. The speed once ascertained, the judgment of the workman will not be required to redetermine it from time to time during the progress of the work. If holding devices be employed of such character that the work cannot be misplaced, about the only thing the operator will have to do that requires judgment will be to see that the proper pressures of the acetylene and the oxygen are maintained, and that the character of the working flame does not change. The ability to do these things is readily learned. There is no welding wire to manage. The chapter on *Sheet Metal Welding* should be carefully studied by the foreman who designs and arranges the work for the machine. He will see that there is a range of possibilities for the supplying of welding material from the work itself. In machine welding, especial attention must be given to securing the work. The working point of the welding flame will move in a straight line placed horizontally. The edges of the joint must be arranged with this fact in view. A portion of the joint which drops below or rises above the standard level may be sufficiently displaced to require a variation in the forward movement of the torch because of the change in the heating conditions. The holding device should be of such a character that the edges are kept throughout at precisely the same level. Again, if the joint varies to the right or left of the line of movement, there will be a variation in the heat-

ing results in the joint. The holding device must, accordingly, be designed to cover this point. In general the requirements as to exact placing of the edges in accordance with what has been explained will not be difficult to meet. But they must not be neglected.

Prevention of Discoloration

In many cases where machine welding is employed it will be possible to eliminate discoloration from oxidation of the surface metal. Thus, the oxidation of steel can often be prevented. Iron oxides are formed at various temperatures. Common rust is formed at ordinary temperatures, but ordinarily only in the presence of water or water vapor. Oxygen is, of course, required. The welder does not have to fear this oxide. However, there is another oxide formed at a pretty high temperature which frequently gives trouble. If oxygen is not present, or is not present until the temperature has fallen below the point at which it forms, then it is not to be feared either. Now oxygen may reach the weld in two ways: it may come (1) from the oxygen supply passing through the tip; or it may come (2) from the atmosphere. With regard to the first possibility, it may be said that a certain portion of the oxygen coming through the tip is required in order to consume the acetylene to carbon monoxide (CO) in the working flame. For this purpose, the oxygen is required to equal the acetylene in volume. That is, the ratio of oxygen disposed of to acetylene furnished is 1:1. In actual practice, it has not been found possible to employ quite so small a proportion of oxygen. It has been found possible in at least one

style of blow-pipe to make the ratio as low as 1.28:1. It is probable that the carbon monoxide and hydrogen passing through the little flame are competent to make harmless a certain proportion of excess oxygen. It will be best, however, to use apparatus where this excess is kept as low as possible. But, even with the best of apparatus, some attention is required to keep the flame to exact form. This is not difficult and means when accomplished that the minimum proper amount of oxygen is being supplied. With regard to the second source of oxygen—the surrounding atmosphere—it is necessary to take especial precautions. There is probably no difficulty at all immediately under the point of the working flame where the heating is being done: the temperature is probably too high and the work is covered by the flame. But, after the torch passes, the temperature will fall and oxidation from the atmosphere is to be feared. A solution lies in excluding the atmosphere. In many cases, this may be done in a simple manner and without expense. I am speaking now of the top side of the joint. If the clamping irons to either side of the seam provide a narrow and rather deep canyon, the outer flame will ordinarily be split into two streamers. One of these streamers of flame will extend for a distance along the bottom of the canyon ahead of the working flame; the other will likewise extend along the bottom to the rear. The streamer which follows the moving torch will exclude the oxygen of the atmosphere from the work; or rather, it will dispose of it by chemical union with it. The outer flame is hot, but it possesses only a moderate temperature as compared with the little working flame. Consequently, after the new weld has passed for a

distance beneath the rear streamer, it will be comparatively cool. All that is necessary as the weld comes out into the air is that the temperature be below the oxidation point. In any particular case, one can readily determine whether the arrangements are adequate. If the size of the streamer is not sufficient to provide a protective covering that is long enough and thick enough, then an auxiliary flame may be used. This should be a reducing flame. A hydrogen jet would be very suitable. This could be arranged to intermingle its flame with the streamer by using a nozzle suitably attached to the under part of the oxy-acetylene torch. The tip of the hydrogen nozzle could be curved backwards, if that seems desirable.

To form the narrow canyon between the clamping irons, arrangements should be such that their lower edges hug the seam pretty closely and that their faces make a steep angle with the horizontal. If they are beveled at 60 or 70 degrees, this result will be attained. To make the canyon deep, we have only to see that the clamping irons are thick. For very thin steel, an inch or an inch and a half will perhaps be thick enough. For heavier sheets, it may be necessary to increase the vertical depth of the faces. The idea is to confine the streamer so as to make it provide a long and thick covering.

In applying this method, the movement of the torch should be continued beyond the end of the seam in order that the rear streamer may have opportunity to perform its duty with reference to the final portion. It may be found necessary also to begin the torch movement somewhat before the work is reached. In either case, the clamping irons should provide the

canyon-like channel for the full length of the torch movement in order to furnish a means of forming the streamers. It is not very clear just why it should (in some cases, at least) seem advisable to begin protection—and with the forward streamer—before the work is reached. However, the reader is advised as to what appear to be the facts.

The foregoing provisions deal with the upper surface of the joint. In some cases, the character of the work or the form of the joint is such that we need not concern ourselves with the under portion. Thus, for example, where the joint is formed by welding together the edges of contacting flanges, there may arise no discoloration on the under surface because of the moderate temperature reached at that point. In other cases, however, it will be necessary to provide especial means. This may be done, under suitable circumstances, by arranging one or more reducing flames along the seam on the under side of the work. A suitable slit may be cut in the supporting table and the reducing flames so arranged as to provide a protective covering sufficiently wide and thick to meet the special conditions.

In perhaps the majority of cases of welding sheet metal, the question of discoloration of the surfaces is a matter of no importance. Under such circumstances, the foregoing directions and suggestions may be disregarded. However, the splitting of the outer flame by the canyon-like arrangement of the clamping irons has a value apart from the question of discoloration. The forward streamer certainly has a heating effect upon the edges to be welded. This will facilitate the work of the little flame and make possible a more rapid operation of the machine. This pre-heating is accom-

plished without expense. Where the canyon-like arrangement is permissible, it should accordingly be employed as a method of partially utilizing the heat of the outer flame.

Some Special Machines

The manufacturer of sheet metal articles may have welding operations whose character and frequency are such as to make a special machine desirable. It will be of advantage then to consider how some special requirements have already been met. What has been done is often suggestive of what may be done.

The Edison Storage Battery Co., of Orange, N. J., employ two special oxy-acetylene welding machines in the fabrication of the containing cans of the elements of their battery. It is necessary that these cans shall be absolutely tight; it is probably not especially essential that the joints have the full strength of the metal. The material employed is sheet steel which has been nickel-plated in advance of the welding operations. Two thicknesses are employed—0.015 and 0.025 inch. This is pretty thin material. To weld it by hand with an edge-to-edge joint would probably be expensive—but perhaps not prohibitively so. The Edison people, however, are doing this work in a highly commercial way, as anyone would grant upon noting the expedition and certainty with which the special machines accomplish the work.

The cans have each a uniform horizontal section, square or rectangular in form. The corners are rounded, however, at a small radius of perhaps a quarter of an inch. Some of the cans have sections of, say,

5 by 5 inches; others of, say, $2\frac{1}{2}$ by 5 inches. Vertically, the cans are perhaps 15 inches in height. There are three seams: one where the edges of the single sheet forming the wall are united; two where the top and bottom are secured to the wall. The vertical joint is made by welding together the edges of flanges which are at right angles to the wall. The flanges are in contact, face to face. An important point to notice is that this seam does not run along a corner; but is located a little to one side. The weld is made by fusing the edges, which are side by side, and permitting the material to intermingle. No welding wire is employed. The seams at top and bottom are identical. The top or bottom is formed in a power press in such a way as to provide a flange all round the periphery. This flange is perpendicular to the general surface of the piece and is perhaps 3/16 or $\frac{1}{4}$ inch deep. There are no joints where the flange turns the corners, or anywhere else. This piece is set in the body of the can, with its concave side on the exterior, and its edge flush with the edge of the wall. The two edges, side by side, are then fused together, just as in the case of the vertical seam. From a welding point of view there is no difference between a top and a bottom. A welding wire is not employed.

In both machines, it is the work which moves: the torch remains stationary. A suitable post stands on the left and to the rear. Upon this is arranged a holding device for the torch. The holding device is hinged to permit throwing the torch back and out of the way when its service is not required. Both types of machine are operated by little individual motors. The drive is transmitted by means of two small disks, one on the

motor shaft and one on the driven shaft. Each of these is provided with two little pins or studs projecting from the face of the disk; these are set diametrically opposite each other. The two disks are so placed as to have the pins of one overlap those of the other. A leather string wound in and out among the pins secures the two disks to each other in a way to limit the strength of the connection. A projecting end of the string does not threaten the hand of the workman as a loose piece of wire would do.

The machine on which the vertical seam is welded is provided with a suitable carriage. The body of the can—without top or bottom—is slipped onto a holding device arranged on the carriage; the vertical seam is placed horizontal with the edges standing up. There are two clamping irons. One moves in a vertical plane on a hinge arranged at one end of the holding device. This clamping iron is brought down upon the work and clamped in position. It is on the side of the seam next the operator. A second clamping iron is also hinged to the holding device and at the same end of it as in the former case. But this second iron moves in a horizontal plane. It has two clamping surfaces at right angles to each other. When this iron has been locked in clamping position, it holds in place the narrow strip of horizontal wall on the side of the seam away from the operator, and also a strip of vertical wall. When both irons are secured, we have the following condition of affairs. The horizontal surface to each side of the seam is securely held in place. Also, the vertical surface adjacent to the nearby corner of the work is clamped tight. The flanges of the work which form the seam lie between faces of the two

clamping irons. These faces together make a narrow and rather deep canyon-like groove with the seam at the bottom. Each face is inclined at an angle of about 60 degrees to the horizontal. The surface of the holding device immediately beneath the seam is provided with a groove in order to avoid the presence of metal in actual contact with the under surface of the joint. One effect of these arrangements is to split the outer flame into two streamers filling the bottom of the canyon to front and rear of the inner or working flame for a distance of perhaps 4 or 5 inches with a fairly deep body of reducing flame. As there is an air space beneath the joint and as air is a very poor conductor of heat, the loss of heat by conduction and subsequent dissipation through radiation is reduced. As the work moves beneath the torch, which is set at an angle of about 45 degrees, the streamers operate to pre-heat the work and to prevent discoloration through oxidation. There is often—perhaps always—some discoloration at the two ends of the seam. It would seem that this might be avoided by extending the movement so as to make the torch overrun at both ends and extending the clamping irons to correspond. The facts are that at present the major portion of the seam can be commercially welded without discoloration either of the nickel plating or steel edges.

The carriage movement is secured by a screw. This in turn is driven by a worm gear meshing with a worm on the shaft driven by the motor spindle. The motor rotates, of course, at a high rate of angular speed. By means of the worm-and-gear and the screw, the carriage is given a slow rectilinear motion of perhaps 8 or 10 inches per minute. It requires about 1¾ min-

utes to perform the actual welding operation. Putting on and taking off the work, and throwing the torch in and out of position increase the total requirement to require altogether perhaps 2½ or 2¾ minutes. Calculating 20 welds per hour and the labor at 30 cents per hour, we have a labor expense of $0.015 per vertical seam. The gases will cost perhaps 1.5 times as much as the labor and thus make the total expense for labor and gases $0.0375 per seam.

The welding of the tops and bottoms onto the shell produced by the foregoing machine is a more complex problem. The shell is held in normal position in a holding device. Within the concavity of the top or bottom a special device is placed which can be opened to spread the flange simultaneously in four directions. Corresponding to this, there is a clamping device outside of the wall of the shell which holds the exterior part of the joint to an exact size and form. This device may be opened and closed, and so provides for ease of engaging and disengaging the shell. That is to say, this clamp is split along a vertical diagonal plane of the can. When the exterior clamp is closed and the interior one opened, the joint is firmly held inside and out. As with the other machine, the entire clamping apparatus is or becomes a part of the holding device. The interior clamp used to expand a top or bottom is a loose piece of apparatus not secured in any way to the main holding device.

The holding device together with clamps and work has to be given a motion such that every position of the double edge of the joint will be carried beneath the torch. It is necessary that the movement shall at all times be uniform, if the best results are to be secured.

At the same time, a moderate retardation will only result in an irregularity in the evenness of the welded edge. The form of the joint covers this. The weld will be made. The movement of the holder is secured through a rack arranged beneath the floor, or bottom of the holder. The pitch line of this rack has precisely the form of the plan of the can. Necessarily it describes a larger rectangle. The reason for this is the sharp curvature of the corners of the plan. As a matter of fact, the radius of curvature of the plan is considerably smaller than that of the pitch line. Now the linear speed of the pitch line of the pinion which drives the rack will give the same rate of movement to the straight portions of the plan. But at the corners, the plan movement would be much less. In order to get uniformity throughout, the pinion is given a much higher speed at the corners. There are eight changes of speed in a complete cycle—two at each corner. However, the design of the machine is such that these changes are brought about automatically. No attention is required from the operator. The machine is so constructed, however, that the rapid movements around the corners can be hand controlled, in case the automatic speed change device should be temporarily disarranged. This requires no really irksome attention on the part of the operator.

The whole apparatus is driven by a horizontal worm direct connected to the individual motor, as in the case of the other machine. Here, however, the worm gear rotates in a horizontal plane. The direct drive of this gear is communicated to a spindle which effects through gears, etc., the drive of the rack around the corners. The necessary speed reduction for the

straight movements is accomplished through certain little gears arranged on a vertical stud projecting vertically from the under surface of the worm gear.

All this will be better understood by considering the sectional views of Figs. 1 and 2. In Fig. 1 the worm-and-gear arrangement is indicated by F, G. Through the gear G a vertical spindle passes. It is retained by suitable bearings in the frame B. The worm-gear is extended upwards to form a sleeve, the whole being arranged to rotate freely on the spindle. On the sleeve is a collar H, which rotates with it, but may be independently moved in a vertical direction. A clutch E is secured to the spindle. One or more teeth are provided on the upper face of the sliding collar. When this collar is made to engage the clutch, the spindle is, in effect, united to the worm gear and rotates with it at the same angular speed. This gives the fast drive for the corners. The gear C, secured to the spindle, drives the gear M, whence the drive is communicated to the pinion N. This last wheel meshes with the rack attached to the bottom of the holding device.

The slow speed is secured as follows: On the under surface of the worm gear G, the pair of little gears I on the stud rotate on it as a unit. It will be noticed that the lower gear of the pair is larger than its companion. On the spindle, a gear J, with ratchet wheel K beneath, is free to rotate. The gear and ratchet wheel are, in effect, a unit. Another gear D is also mounted on the spindle but not loosely. When the clutch at the top of the spindle is out of action, the drive is effected through the tight gear D. As the worm gear moves round, the lower one of the little pinions will simply roll on the gear J, if the latter is

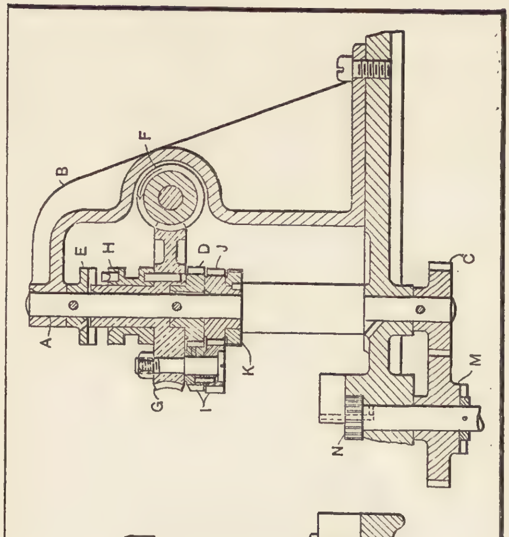


Fig. 1

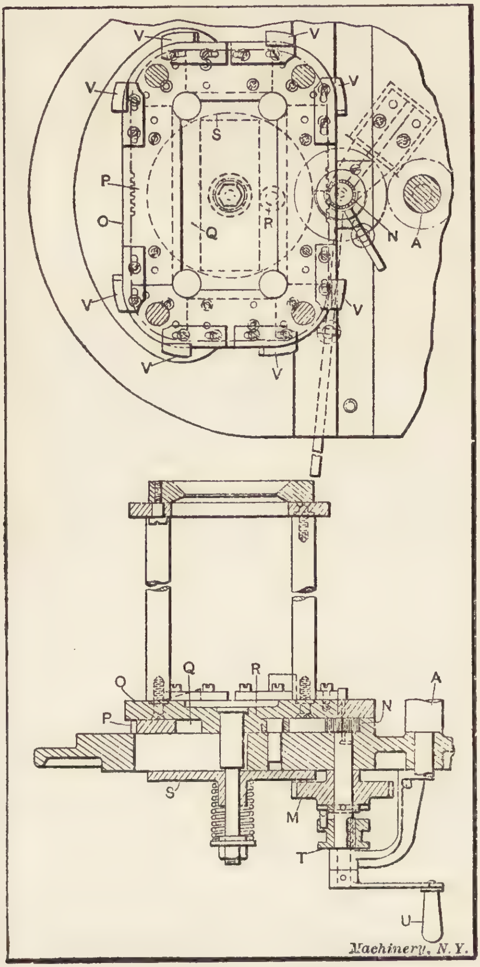


Fig. 2

held stationary. A ratchet finger arranged on a post mounted on the frame of the machine performs this duty through the ratchet wheel K. The smaller and upper pinion is compelled to rotate with its companion. Because it is smaller, it will, however, have a different pitch line rate. In consequence of the foregoing arrangements and facts, the spindle will be driven through D at a slower angular rate than when the spindle is unified with the worm gear. This drive is used for the straight portions of the rack.

In Fig. 2 we have the gear M again. The bottom of the holding device is the table O. At P, we have the rack. At Q is a channel which lies within the rack and has the same general form as that of the rack's pitch line. The inside wall of this groove or channel has, however, sharp corners instead of rounded ones. A roller X engages this groove. It is located directly opposite the driving pinion and furnishes a rolling, resisting surface on which the pinion may roll the rack along. There is a sliding plate S. This is held in place by a bolt and a spring. By its means the holding device is kept in an upright position, the spring having the effect of relaxing the rigidity of the arrangement. The foregoing provisions are found sufficient to impart the requisite movement of the entire holding device.

The rapid and slow movements are effected by lifting and depressing the sliding collar H so as to engage and disengage the clutch E (Fig. 1). By the use of little blocks placed at the proper points and of a level and fork control of the collar H, the clutch is thrown in and out automatically as the table of the holding device is driven through its movement. The operator

stops the machine, takes out the old work, puts in new, adjusts the clamps, starts the machine and cares for the torch. All of these are simple operations and require the exercise of nothing more than a very moderate amount of judgment.

Tube Welding Machines

In Germany, the application of the gas welding machine to the manufacture of the smaller diameters of tubing is no theoretical process. It is hard to say what diameter is the upper limit, as there are one or more styles of welding machine which broaden the track of the torch and thus permit grooves other than the narrowest to be heated. Specially formed edges permit the elimination of the wire. We shall probably not be far wrong in saying that at present the well-ascertained practice in the machine welding of tubes is only limited at the point where wire must be employed.

Tubes that are rolled for machine welding must be formed with considerable precision. This applies not so much to the question of roundness as to the character of the joint. If the welding is to be done upon edges which have been unprepared, it will be important that closure be really effected. Edge should be in actual contact with edge. In many cases, this will require that a natural tendency to spring apart must be corrected. Then, the levels of the two edges must everywhere match. In short, the joint must be a perfect one. All this it is possible to get. The writer has seen a sample of tubing that had been rolled but not welded in which the joint was so perfect that inspection by the eye was insufficient to determine whether there

was a joint. It might have been a piece of cold drawn seamless tubing, so far as his inspection went. There is no doubt, then, that the rolling can be done with all the necessary perfection. As to whether such rolling is commercial, the reader can judge when he learns that a single inexpensive machine has a capacity of four miles per 10-hour day for tubing $\frac{3}{4}$ inch in diameter and having a wall of $\frac{1}{8}$ inch.

The stock is in the form of a long ribbon of sheet steel. It first passes between two rolls arranged to rotate in vertical planes which bend up the two edges of the ribbon. It is important that the curvature shall be exactly that of the finished tube. If the material is elastic, a ridge may be put in along the axis of the ribbon, the convexity of this protuberance being arranged upwards. It should not be sharp. Subsequently to the closure of the tube, this interior ridge will be gotten rid of by the use of a proper mandrel. Another pair of vertically rotating rolls receive the ribbon and bend it to form a tube with a very wide opening at the top. It may now be run through a pair of horizontally rotating rolls which succeed in closing the tube by their lateral pressure. There is, after this, but little to do except perhaps force the tube over a suitable mandrel for the purpose of perfecting the form. Such machines are suited for the smaller sizes of tubing—e. g., for those used for gas or water. The wall thickness may be $\frac{1}{8}$ inch or less. A separate appliance performs the duty of cutting the tubing off at desired lengths.

In the manufacture of tubes of large diameter, the process of rolling parallel to the axis of the tube is apparently unsuitable. Consequently, the continuous

procedure has to be given up in their case. Suitable lengths are fed into machines whose rolling devices have their axes parallel with the axis of the tube. That is to say, the work begins on the entire length of one edge of the seam. In this way, tubes of considerable size can be rolled from sheet metal. Diameters up to 10 inches can be handled by machines already on the German market. These machines handle material up to ¼ inch thick.

The welding machines for the work where no broadening of the flame track is necessary may be quite simple affairs. The essentials are few. First, there must be a means of carrying the length of tubing along at a perfectly regular rate of speed. In one style of machine, at least, this is accomplished by using two pairs of grip or pressure rolls. These pairs are placed a short distance apart. A suitable post and holder for the torch is also required. The third requirement—and a very important one it is, too—relates to the control of the seam. It is very necessary that its position relative to the working flame shall be quite exact. It must not vary either up or down or to right or left. A method of control makes use of a disk with a sharp edge. This is placed at a point a little in advance of the welding position. The edge penetrates into the joint and thus secures control. These are the essential requirements. Pre-heating, while not essential, is quite important. To effect it, the unwelded tube may be passed through a muffle or similar device. It is said that double the ordinary speed of welding can be attained by pre-heating. This means a great saving.

The writer does not know of its application to the pre-heating of tubes, but there seems to be no good reason why the outer flame of the torch should not be

applied to this purpose. In such a case, metal surfaces may be provided on either side of the working flame. These should form a narrow and deep groove with the moving joint at the bottom. They should extend both to the front and to the rear of the working flame. The heat from the outer flame costs nothing extra. The foregoing arrangements could probably be used with advantage even in connection with a special pre-heating device. They simply provide for the partial utilization of part of the outer flame.

With an absolutely tight joint formed by rolling, the loss of thickness along the weld should be very inconsiderable. Even this slight loss may be obviated by suitably forming the edges to provide material for the purpose.

In the case of tubes having walls too thick to be commercially dealt with in an adequate manner without providing for the penetration of the working flame, the edges should be specially prepared. Indeed, the thicker material will form a groove even if the edges are unprepared. The reason for this is that the exterior circumference of an annular ring is longer than the interior one. If an ordinary strip of ribbon be bent around until the inner edges just touch, there will not be enough material to close the joint on the outside. While the resulting V-shaped groove might perhaps permit the penetration of the working flame, a weld made without additional metal would mark a location of reduced thickness. By giving the edges a very steep bevel and providing a rib along the summit of the bevel, we may arrange adequately for penetration and for new metal.

If it is desired to restore the metal of a steel tube

to its original strength, it should be properly annealed in a suitable retort. On the other hand, the location of the weld can be strengthened by providing an excess of material. If this metal overflows the sides of the groove, the width of the heated track of the working flame must be sufficient to fuse the surface with which the overflow comes into contact, in order to secure adequate union. A method has been devised abroad whereby the torch is given a circular or other motion adapted to widen its influence. If the whole circumference of the tube is pre-heated, an annealing procedure will be a necessity, unless the temperature of pre-heating is not permitted to rise above the temperature of best grain size—see chapter on *Restoration of Steel.* Otherwise, the walls of the tube will have less than the maximum tensile strength. In some cases, it may seem simpler to provide for strength by increasing the thickness of wall.

CHAPTER X

Oxy-Acetylene Cutting Torch

THE oxy-acetylene welding torch may be employed in the cutting of steel, if a suitable auxiliary oxygen jet be provided. The oxygen jet, which is ordinarily under higher pressure than the welding oxygen, is arranged close up to the welding jet. To perform the cutting operation, the welding jet is used alone for a short time to heat the initial point of the cut. When the metal has reached a white heat, the oxygen jet is started. By moving the two jets along at a rate dependent principally upon the thickness of the work a narrow, clean cut can be made. The metal cut out passes away in the form of a stream of sparks. The operator works from one side only. He can cut pretty much any work of reasonable thickness upon which he can bring his jets to bear. The sparks must have an exit; but it is not always necessary that they should have this on the opposite side of the cut. For example, the boring of a hole is an ordinary cutting operation. Here the sparks do not find exit on the opposite side until at the close. However, it is preferable to provide for the discharge of the sparks on the other side of the work.

It has been used to provide three supply tubes for the cutting torch. By means of an improved device,

the Davis-Bournonville Company are able to eliminate one of the supply tubes. That is to say, all the oxygen is brought in through a single tube. The pressure will be the maximum required. There are indeed three short metal tubes connected with the tip holder, and these tubes carry the acetylene, the heating oxygen and the cutting oxygen. But these three tubes are not properly a part of the supply system, being in fact a part of the shank or handle of the torch. These tubes are arranged in a kind of envelope at the rear end of the torch, the two supply tubes entering the envelope at one end and the three shank tubes issuing from it at the other end. Within this envelope the oxygen is divided into two streams, one for the heating jet and one for the cutting jet. By means of a small piece projecting from the forward wall of the envelope, a movement of the thumb or finger will suffice to close or open the conduit carrying the cutting oxygen to the tip. A needle valve on the envelope enables the operator to regulate the flow of the heating oxygen independently of the cutting oxygen. Further, a cock arranged near the rear end of the envelope provides a means of opening up or shutting off the entire gas supply without interfering with the arrangements for controlling the various pressures. This is a valuable feature, since it permits almost instantaneous resumption of work with precisely the same conditions existing at the moment of stopping. This two-hose torch is adapted for either hand or machine use. A hand torch of this description has cut in two a 12-inch I-beam in 80 seconds, the oxygen pressure being at 26 pounds per square inch.

As to precisely what happens when the cutting

action takes place, there would seem to be some doubt—at least as to details. It may be useful, however, to have a statement of what seems to be probably the facts in the case. At a fairly high temperature, the iron in the steel which is uncombined with carbon—i. e., the ferrite—unites with the oxygen supplied by the cutting jet to form magnetic oxide of iron (Fe_3O_4). Also at high temperatures, the iron carbide of the steel is broken up into iron and carbon, these two substances uniting with the oxygen to form magnetic oxide of iron and carbon dioxide. These chemical changes are, all but one, combustions. We may accordingly regard the cutting action as a *burning up* of the steel involved.

Assuming the foregoing account to be substantially correct, it will not be difficult to see that it will be necessary to supply a sufficient quantity of oxygen to form the various combinations. In calculating the necessary amount of oxygen, we may be in error to a small extent only, if we consider the steel to be all iron. This is because even the highest carbon steels contain but a small proportion of carbon. The atomic weights are: Fe, 56; C, 12; O, 16. The composition of the iron oxide in question is given by the formula Fe_3O_4. We find, at once, that the weights of iron and oxygen are in the ratio of 168 and 64, or 21 and 8. That is, the oxygen needed will be 8/21 times the weight of the steel involved in the cut. The oxygen will, accordingly, weigh 38 per cent. of the weight of the steel removed. If the cut has a thickness or width of ⅛ inch, the weight of steel corresponding to each square inch of the face of the cut is 0.0352 pound. The weight of oxygen necessary for combination with

this steel is, accordingly, 0.01338 pound. As a pound of oxygen at 32 degrees Fahrenheit, and barometric pressure of 29.9 inches, occupies 11.2 cubic feet of space, we conclude that a square inch of cut requires 0.15 cubic foot of oxygen for the chemical combinations with the iron and carbon of the steel.

Now we must not expect to do the cutting with no more oxygen than this. We must be prepared to waste some of the gas. To have no waste would require that we supply the oxygen continually in just the right amount to combine with the iron and carbon and at the precise points. It is scarcely reasonable to demand this. The practical thing to do is to furnish an excess. It will be well, perhaps, to provide 50 per cent. more than the theoretic amount. In other words, we shall expect to use 0.23 cubic foot of oxygen in the cutting jet for every square inch of the face of the cut.

Practical tests show that this estimate is about right. Thus, a series of 38 cuts of miscellaneous size of face were made on a single day. The areas of the faces ranged from 1.56 square inches to 75.60, the average being 16.20. The total area amounted to 615.56 square inches. The oxygen used for cutting purposes was 155 cubic feet. The average per square inch is accordingly 0.25 cubic foot. On another day, a series of 16 cuts were made, the areas varying from 5 square inches to 21. As the total area cut amounted to 187.46 square inches, the average face had an area of 11.72 square inches. The amount of cutting oxygen used was 37.5 cubic feet; so that the average per square inch was 0.20 cubic foot. The excesses beyond the theoretic amount disclosed by these two tests were 67 and 33 per cent. We shall, it would seem, not be

far wrong in assuming the excess to be 50 per cent. for work neither very thin nor very thick. That is to say, such work will require cutting oxygen to the amount of 0.225 cubic foot per square inch of face cut.

The heating flame has to be maintained independently of the cutting jet. This flame consumes both oxygen and acetylene, though in amounts considerably less. In carrying out the two series of tests already mentioned, the heating oxygen employed was also made a matter of record. The heating oxygen used in connection with cutting the 615.56 square inches was 40 cubic feet; in connection with cutting the 187.46 square inches, 5 cubic feet. The averages per square inch were 0.065 and 0.027 cubic foot. The difference in amount is to be explained as due, in part at least, to the fact that the work in the one case was, on the average much heavier. The respective average areas of the faces of the cuts were, as already stated, 16.20 and 11.72 square inches. The heating of the heavier work would presumably call for a greater expenditure of heat than the increase in the size of the cut would cause us to expect. This is reasonable because the dissipation of heat turns largely on the volume of the work and so is proportional to the cube of a given dimension, whereas the area of the face of the cut is proportional to the square of that dimension.

We may take the average as a fair rate of oxygen consumption for the heating jet. Each square inch of the face of an ordinary cut will, accordingly, require about 0.046 cubic foot of oxygen. As oxygen and acetylene are used in one or more of the best torches, in the ratio of 1.28 to 1, we estimate that 0.036 cubic foot of acetylene is employed in connection with

cutting a square inch. If we look on the work included in the two tests as average work, we may summarize the gas consumption thus:

Gas Consumption for Average Miscellaneous Cutting

Oxygen for cutting jet, per square inch of face of cut.............0.225 cubic foot
Oxygen for heating jet, per square inch of face of cut.............0.046 cubic foot
Acetylene for heating jet, per square inch of face of cut.............0.036 cubic foot

If we estimate the cost of oxygen at 3 cents per cubic foot, and of acetylene at 1 cent per cubic foot, we readily calculate that it will cost $0.0085 per square inch for all gases used in cutting average work. When oxygen is produced at 2 cents and acetylene at 0.75 cent, we get $0.0057 as the cost per square inch.

In order to estimate the labor cost, it is necessary to inquire as to the time occupied. The actual cutting time, including the preliminary heating at the beginning of each cut, and the ordinary intervals between cuts, was for the total of 615.56 square inches about 125 minutes. This gives an average of 0.23 minutes per square inch. If we estimate the labor at 20 cents per hour, we have for the labor cost per square inch, $0.00115. If the labor is worth 25 cents per hour, the cost per square inch is $0.00096. Taking the higher estimate for cost of gases and the higher one for cost of labor, we have $0.00965 as total cost per square inch. Taking the lesser values for gases and labor, we

have $0.00666 as total cost per square inch. The reader can readily estimate the combination of high cost of gases and low cost of labor, and the reverse combination. The estimates of gas consumption and of labor time can, of course, be made the basis of the cost calculation when the rates for these items are different from those assumed.

The Preliminary Heating

The heating preparatory to beginning the actual cutting operation greatly varies. It may be as little as nothing at all. A very little experimentation with a given line of work will make clear to the observant workmen an advantageous way of getting a start. Thus, out of 76 experimental cuts, in which the minimum dimension was 1.25 inches, 19 cuts—25 per cent. —were begun at once. The smaller of the two dimensions in each of these cuts make up a series ranging from 1.25 to 2.75 inches. In five identical cuts—2.75 by 3.25 inches—by the same operator, the preliminary start ran through the series 5, 10, 15, 20, 25 seconds. The actual cut was made just as quickly with a 5-second start as with any of the others. In fact, the minimum time the oxygen cutting jet was on was 55 seconds and this period followed starts of 5 and 20 seconds. For these five cuts the average start was 15 seconds; and the average period of actual cutting 61 seconds. The largest period required to get a start was with a cut 5.5 by 10 inches. Here, 10 minutes were required to effect a start. However, the remark, "Chipping sand in casting," is appended to the record

of this cut. The period for the cutting jet was 13.5 minutes.

The writer is informed by one of the leading concerns engaged in the manufacture of oxy-acetylene torches that they have reduced the ratio of oxygen to acetylene to the very low value 1.13:1 We may expect the cutting expense to be reduced because of the reduction in the amount of oxygen consumed by the heating jet.

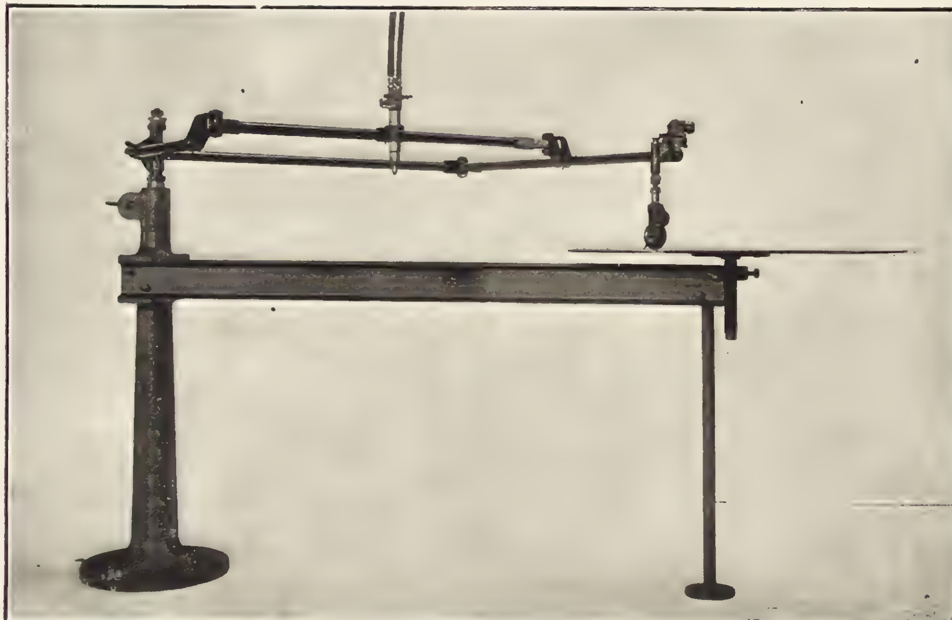
CHAPTER XI

Cutting Machines

A NUMBER of machines have been devised for cutting. One of the most noteworthy of these is the *Oxygraph*. By means of this device the operator is able to direct a tracer over the outline of a drawing or other representation of the design to be cut. The cutting torch will then be carried by means of connected mechanism over the face of the work, making a cut of precisely the same form as the pattern. The principle underlying the well-known drawing device known as the pantagraph is utilized. It is possible to make the design actually cut of a determinable size different from that of the pattern. The tracing mechanism is provided with a wheel mechanically driven. This arrangement secures mechanical propulsion for the whole pantagraph structure. In one form, the wheel is driven by electric power, a suitable motor being carried on the machine itself. The operator will, accordingly, not be concerned with supplying the energy for propulsion, but with guiding the tracer accurately over the pattern. A suitable device is arranged to give him control of the direction taken by the forward moving wheel. The cutting torch may have a circular heating jet surrounding the oxygen cutting jet. In this case, it will be unnecessary

to rotate the cutting torch. But where the heating oxygen is supplied from a single orifice, it may seem desirable to rotate the heating jet in order to distribute the heat all around the point at which cutting is taking place. One style of this machine provides for this by connecting the torch and tracer by means of sprockets and chains. It is possible in this manner not only to rotate the torch but to do so in relation to the rotative movement of the tracer wheel. This machine will, it is said, cut steel 3 inches thick at the rate of six linear inches per minute. With this machine, not only curves and unbroken straight lines can be cut, but angular forms as well.

The universal welding machine designed by the Davis-Bournonville Co., New York City, and described in the chapter on *Machine Welding,* can also be used for the purpose of cutting. When so used, both thin and thick steel may be cut. In fact, whatever thicknesses and materials come within the range of the hand operated cutting torches can be dealt with by this power driven machine. It is said that even greater thicknesses can be cut where the machine is used than where the hand of the workman has to be relied on. The advantages of the mechanically operated cutting apparatus are largely the same as those which exist with machine welding. The heating and cutting jets are maintained in an exact relation to the work and are driven forward at a precise and regular speed. In welding, damage to the work may at times result from lingering too long; in cutting, lingering too long wastes the gases, especially the oxygen of the cutting jet which is ordinarily under fairly high pressure.



The Oxygraph

The power driven machine can be operated at precisely the speed which has been found best for the work in hand. Moreover the mechanically operated cutting apparatus produces a cut whose path has an even and precise form.

With the universal welding and cutting machine of this company, the ordinary form of the heating torch with oxygen jet attachment may be employed. A special form of torch is preferable, however. The precision of control enables comparatively unskilled labor to be employed in connection with repetition work. Further, the consumption of gas—especially oxygen—can be reduced to a minimum for the same reason. The designers of this machine have taken a further step. They have designed a method of cutting in which the oxygen cutting jet is employed with two heating jets—one ahead and one behind. The one to the rear is smaller than the other. Its office seems to be the prevention of the dissipation of heat at the cutting point. Three flexible tubes bring the gases to the machine. One carries the oxygen under high pressure. The others supply oxygen and acetylene for the heating jets.

The same company has developed a mechanical method of cutting off steel tubes. Normally, it is used with the tube in a vertical position. A collar is arranged to envelop the tube, and is provided with means of temporary attachment. A second ring is rotatably arranged on the collar and carries the cutting apparatus. The ring is provided with a worm gear with which a worm arranged on the collar is in mesh. By means of a hand crank, the worm is rotated with the

result that the gas jets are carried around in an exact circle with their action on the tube everywhere the same. It is not difficult to operate such an apparatus with steadiness by hand.

Two other mechanical devices have been developed which will prove of value for service in connection with the erection and fabrication of steel structural work. One of these appliances is of such a character that it can be attached to an I-beam for the purpose of making a transverse cut across it. Then a slight movement causes the cutting torch to assume the correct position for a cut at right angles to the length of the beam. The other device is a perforating machine, suited to piercing I-beams.

CHAPTER XII

Does Oxy-Acetylene Cutting Injure the Metal?

A QUESTION in which many users of the process of cutting with the oxygen jet are, or should be, interested relates to any influence which may be exerted upon the material in the vicinity. The temperature of the metal in the actual cut rises to, say, 2700 degrees, Fahrenheit, or perhaps even more. The conductivity of steel is pretty high, so that we are not permitted to conclude too quickly that this excessive temperature does not affect the adjacent material. It is of importance to consider results obtained in some experiments abroad.

First, consider the case of a piece of sheet steel about 1.18 inches thick. The carbon content was 0.30 per cent.; silicon, 0.02 per cent. A sample piece was first cut off by a cold process (No. 1). An oxy-acetylene torch with oxygen jet was then used to make a cut. Two sample pieces (Nos. 2 and 3) were now cut by cold process from the sheet on one side of the oxygen cut. That is to say, No. 2 was a strip on one side of which the oxygen jet had passed; and No. 3 was a strip taken alongside. These strips had been, one

of them, absolutely next the heat; the other, but a short distance away. Chemical analysis disclosed no alteration in the carbon content. The elastic limit of the piece next the oxygen cut (No. 2) was found to be 39,601 pounds per square inch; and the ultimate strength, 66,570 pounds per square inch. In fact, the elastic limit and the ultimate strength were each a trifle higher than the same qualities of No. 1, the piece cut off by cold process before the oxygen cut was made. No. 3, the piece cut parallel to the oxygen cut but at the width of No. 2 from it, had the lowest elastic limit (38,466), and the highest ultimate strength (66,996). However, the differences are so small that they could readily be accounted for by local differences in the material apart from the oxygen jet and by errors in the tests. The elongation disclosed by No. 1 was somewhat smaller than was the case with the other two. The amount of contraction was the same for all. In view of the foregoing facts, we are entitled to conclude that the cutting jet of oxygen did not appreciably affect the tensile qualities of the metal in the vicinity.

Another experiment was tried with a piece of cast steel of 0.16 carbon percentage. The silicon percentage was 0.18. The thickness here was about 5.12 inches. A number of test pieces were taken. One of these (No. 3) came from a position alongside an oxygen cut; the others were obtained from points at some little distance. The elastic limit and the ultimate strength of No. 3 were found to be greater than the same qualities of every one of the other samples. The values were 34,349 and 51,208 pounds per square inch respectively. Altogether, the results of this experi-

ment are to be understood as disclosing no tensile deterioration in the metal next the oxygen cut.

A nickel steel was also tested in a similar way. The composition of this steel was, as to carbon, 0.12 per cent.; as to nickel, 4.11 per cent. The thickness was nearly 6 inches (about 5.9 inches). Rather more than ordinary interest attaches to this case because the nickel steel had been given a treatment. One might well consider whether the good effects of this treatment might not be destroyed, at least in the immediate vicinity of an oxygen cut. The tests made of the sample from a point close up to the cut and of others somewhat distant showed that the tensile qualities were practically the same. The carbon content of the nearby sample was a little short of the supposed amount, but it was up to the average of the three distant samples.

Still another experiment was carried out; this time with a hardened nickel-manganese steel. The thickness of the plate was 0.67 inch. The chemical constitution here was, as to carbon, 0.25 per cent.; as to manganese, 0.98 per cent.; and as to nickel, 2.84 per cent. Considering the tensile tests as a whole, one draws the conclusion that the oxygen cut does have an effect for at least the distance of one inch from the cut. To put the results comprehensively, the effect seems to be that of a partial nullification of the hardening treatment. The Brinell test for hardness was also applied, the result being that the reduction of hardness ceased at or before the distance of 1.4 inches from the cut was reached.

Perhaps, the foregoing may be summed up thus:

(1) Untreated steel having a combined carbon-sili-

con percentage less than 0.35 can be cut with the oxygen jet without any change being induced.

(2) Treated nickel steel having a small carbon content is unaffected.

(3) Hardened manganese-nickel steel with a considerable carbon content (say, 0.25 per cent.) is liable to be softened for a distance of 1.4 inches.

Taking our stand partially upon what has been said, we seem entitled to conclude that the passage of the jet has no decarbonizing effect on any of these steels.

CHAPTER XIII

Miscellaneous

Welding Rod

WELDING ROD FOR CAST IRON.

A CAST iron rod having the following composition is recommended as well suited for cast iron: C, 3.90; Mn, 0.56; S, 0.093; Si, 2.86; P, 0.75. In making the rod a small addition of ferro-titanium should be made while the metal is in the ladle to remove oxygen and nitrogen. The weld produced with such a rod will have a close texture and be easy to machine.

In making welds of cast iron, a difficulty arises in connection with the hardening of the metal at the weld. It sometimes becomes so hard as to prohibit or make very difficult any machine operations. Or, the weld may become porous. The problem would now seem to have been solved by a procedure patented in Germany and perhaps elsewhere. The idea is so to modify the new material added as to produce a metal that can be readily machined. The weld is made with cast iron, but ferro-silicon and graphite are added. Or, one may use an iron alloy rich in silicon and carbon as including all that needs to be added. It may, at times, be necessary to use a special powder in connection in

order to insure a thorough intermingling of the cast iron and the added material. This powder may be made by mixing such flux materials as borax, soluble glass, etc., with a salt yielding oxygen (e. g., chlorate of potash). The office of the oxygen thus set free is to unite with any excess of carbon and silicon possessed by the added material.

The hardening of a cast iron weld may often be prevented by proper management of the cooling. For example—suppose we have just concluded the filling up of a blow hole in a casting. The amount of new material is in such a case small compared with the surrounding mass. Unless preventive measures are taken, we may expect a very rapid cooling and a consequent hardening. One method of retarding the cooling is to heat the metal immediately surrounding the filled-up blow hole, using the welding torch for the purpose. The flame is circled about the blow hole—first close up, then further away. In this way the conductive effect of the old metal surrounding the new is partially destroyed. Continue this procedure and thus secure a gradual cooling.

WELDING ROD FOR MALLEABLE IRON.

When malleable iron is to be united to malleable iron or to mild steel, use a mild steel rod wrapped in a coil of copper wire.

WELDING ROD FOR FERRO-STEEL AND WROUGHT IRON.

Do not use steel rod when welding cast ferro-steel onto wrought iron. The trouble which results seems to be a porous condition of the weld—not simply in one place, but everywhere. Use a cast iron rod, em-

ploying a mixture of borax and salt as a flux. This procedure is said to produce a fine weld.

WELDING POWDERS.

The following recipes for welding powders are given as suitable for the purpose indicated:

In welding *steel to steel,* the powder employed may be made of these ingredients: 50 parts, borax; 30 parts, iron filings; 10 parts, sal ammoniac; 10 parts, copaiba balsam.

In welding *steel to iron,* the powder employed may be constituted as follows: 35.6 parts, boracic acid; 30.1 parts, table salt; 26.7 parts, prussiate of potash; 15.3 parts, potash; 8 parts, soda.

The advantage to be gained by the copaiba balsam and the prussiate of potash would seem to be in the prevention of decarbonization at white heat.

CONCERNING THE GASES.

Users of the oxy-acetylene process must bear in mind that they cannot expect the best results unless they give strict attention to details. A very important matter to be considered in this connection is the question of the purity of the gases used. It has been found, for example, that the cutting effectiveness of oxygen is very rapidly impaired as the impurity of the gas increased. Five or six per cent. impurity is sufficient to decrease the cutting ability to a very large extent.

Oxygen is commercially produced in three ways: (1) by the decomposition of water; (2) by separation from the nitrogen of the atmosphere; and (3) by chemical means. One usual method of decomposition is by passing an electric current through acidulated water.

The impurity to be guarded against here is hydrogen. If the oxygen is intended for cutting, it is very necessary to eliminate this impurity to the point where only a trifling percentage remains. When oxygen is obtained from the atmosphere, the impurity is principally nitrogen. A small percentage of this gas will probably have only an inconsiderable effect in welding. If the oxygen is obtained by a chemical process, chlorine gas is apt to be present. A small percentage of this impurity is very detrimental in welding operations.

If the user is making his own oxygen, he should see to it that he has thoroughly reliable apparatus and that he is carrying out the process of manufacture in a thoroughgoing and scientific manner. In other words, he should let no uncertainty attach to the matter of the purity of his oxygen. If he buys his oxygen, then he should either subject it to careful inspection or make sure he is getting it from a reliable concern.

With regard to acetylene, the question of the character of the gas used is perhaps of still greater importance. It is not so much that the acetylene is liable to include some foreign gas. That is not the thing to be feared. The acetylene itself through overheating may have its own character changed. That is to say, the acetylene may become polymerized. This result is equivalent to the introduction of impurities; for the overheating of the gas occasions the production of tar vapors within it. Such impure acetylene will not give the best results in respect to the production of heat. In addition, the tar vapors tend to clog the piping and the torch.

There are three methods of generating acetylene from calcium carbide. In all these methods, the results are

obtained by mingling water and the carbide. The several systems differ in the way the two substances are brought together. In the recession system, the carbide is placed on a kind of grate and water is admitted from below. A difficulty here arises from the fact that the water is hindered from access to the carbide by the expansive power of the gas. As acetylene is generated, it operates to drive the water away. Because of the insufficiency of the amount of water, a great deal of the heat generated operates upon the gas itself. An overheated, polymerized gas is apt to result. In accordance with a second method of manufacturing acetylene, water is sprinkled onto the carbide. This is said to be some improvement upon the recession process. When one reflects that one pound of calcium carbide is competent to impart a boiling temperature to six pounds of water, he is prepared to learn that the sprinkling procedure is regarded as inadequate. What is needed is absolute immersion. This is the third method. The carbide is dropped into a bath of water. This is without doubt a most effective process. But even here there are differences of excellence. If the carbide is fed in lumps of considerable size the generation of acetylene does not all take place immediately or even soon after a lump touches the surface of the water. Generation of gas begins at once; it continues, however, as the lump falls through the water. The heat generated is distributed through the water. Lump or nut carbide is carbide that will not pass through a screen of ¼-inch mesh. The lumps may be 1¼ inches long and ⅜ inch thick. It is said that more gas can be generated from the lump size than from smaller sizes.

WELDING MATERIALS AND SUPPLIES.

It is to the interest of the manufacturer of high grade welding apparatus that the user succeed. The importance of using welding rod suited to the particular work in hand is well known to him. Unless the user is sure of his own knowledge, it is ordinarily better for him to depend upon the advice given and the welding rod supplied by the manufacturer. The same thing may be said as to fluxes. Unless you know, go to the reliable manufacturer of apparatus and get your supplies from him. Your extra expense will be more than justified by the increased certainty and quality of your success. It is very poor economy to make an inferior weld because of an unwillingness to pay a little higher price for supplies.